STUDIES ON VARIABILITY, DIVERGENCE AND IMPROVEMENT OF *CURCUMA AMADA* ROXB. AND *KAEMPFERIA GALANGA* L.

Thesis submitted in part fulfilment of requirements for the Degree of Doctor of Philosophy in Botany of the University of Calicut

by

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CERTIFICATE

Certified that this thesis entitled "**Studies on variability, divergence and improvement of *Curcuma amada* Roxb. and *Kaempferia galanga* L."** embodies the results of a piece of bona fide research work carried out as part fulfilment of requirements for the degree of Doctor of Philosophy in Botany of University of Calicut by Ms. M. Jayasree under my guidance and supervision and that no part of the thesis has been submitted for any other degree.

I further certify that such helps or sources of information availed of in this connection have been duly acknowledged.

Calicut University (Dr.K.V.MOHANAN)

14 May 2009

DECLARATION

I, M. Jayasree, hereby declare that this thesis entitled "**Studies on variability, divergence and improvement of *Curcuma amada* Roxb. and *Kaempferia galanga* L."** being submitted in part fulfilment of requirements for the Degree of Doctor of Philosophy in Botany of University of Calicut embodies the results of a bona fide work done by me under the guidance of Dr. K. V. Mohanan, Professor & Research Guide, Genetics and Plant Breeding Division, Department of Botany, University of Calicut and that no part of it has been submitted for any other degree.

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PREFACE

The members of the monocot family Zingiberaceae are famous for their medicinal, spice, food and ornamental values. Some of the members of the family have already been studied at different levels, but, some of them are yet to be analyzed elaborately based on theoretical as well as applied perspectives.

Curcuma amada Roxb. and *Kaempferia galanga* L. are two such species of the family which demand studies based on different aspects. Both the species are comparatively underexploited and their economic potential has also been studied only to a limited extent.

Both these species, even though being cultivated in the homestead gardens of many countries of the tropical world, face the threat of marginalization due to commercialization of agriculture and elimination of many species from the diet and medicine of man. Moreover, the genetic diversity of both these species has not been studied considerably and it leaves a lacuna of knowledge in the case of the genetic base and improvement potential of them.

The present study is an effort to analyze the variability and interrelationship of agronomic characters, character association, genetic divergence and improvement potential of *Curcuma amada* Roxb. and *Kaempferia galanga* L. based on the accessions collected from Kerala State of India.

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Chapter I

INTRODUCTION

The family Zingiberaceae occurs chiefly in the tropics of the world with about 53 genera and 1200 species (Kress *et al*., 2002). It is one of the ten largest monocotyledonous families in India. It is represented by 22 genera and 178 species in India and by 9 genera and 70 species in South India (Jain and Prakash, 1995; Sabu, 2006).

The Zingiberaceous plants form an important group with considerable economic potential. The members are cultivated for their uses as spices, medicines, condiments, flavouring agents, fresh vegetables, tuber crops and recently as cut flowers. The presence of essential oil has made some of the species important since the time of ancient Greeks. *Elettaria cardamomum* Maton, the small cardamom of commerce is the second most important spice of India. *Curcuma longa* L., turmeric is known as ‘golden spice’ as well as ‘spice of life’. Ginger is being used medicinally in India from ancient days itself and it is known as *mahabheshaj* and *mahoushadhi* in Sanskrit (Ravindran and Nirmal Babu, 2005; Sabu, 2006; Ravindran, 2007).

The members of Zingiberaceae are annual or perennial rhizomatous herbs. The rhizome is sympodially branched and composed of distinct segments (Tomlinson, 1956). The rhizomes are variously coloured ranging from pale yellow, deep yellow, greenish blue, pink or combinations of these in different species. The young rhizomes and axillary buds are protected by scale leaves. Leafy shoots are generally unbranched and true aerial stem is present in some

genera and absent in others. True stem is very short as in *Kaempferia* or pseudostem with clasping leaf sheaths is present as in *Curcuma*. The leaves are distichous and they exhibit morphological variation in structure, shape, size, texture and venation (Sabu, 2006).

Curcuma amada Roxb. and *Kaempferia galanga* L. are two species of the family Zingiberaceae with economic potential. The former is used in medicine and also has food value whereas the latter is important as spice and medicine. Both *Curcuma amada* and *Kaempferia galanga* are propagated vegetatively by rhizome.

Curcuma amada Roxb. is an underexploited spice crop which grows luxuriantly on the tropical soils. The plant grows wild and also is cultivated as an annual. It is known as mango ginger in English, *karpuraharidra* in Sanskrit, *amada* in Bengali and *manga inchi* in Malayalam. The plant is a native of Bengal but now it is cultivated throughout India. The specific epithet *amada* is derived from Bengali meaning mango ginger referring to the rhizome having characteristic taste of unripe mango (Saji and Sasikumar, 2004).

Curcuma amada Roxb. is a rhizomatous aromatic herb with pseudostem and petiolate leaves. Inflorescence is lateral or central in position with sterile light violet terminal comma bracts. The underground part is the rhizome which is branched and showing sympodial growth (Warrier *et al*., 1994; Sabu, 2006).

The tubers are regarded as cooling and useful in prurigo. They are employed as carminative and stomachic (Watt, 1972). The rhizome is used for preparing salads, chutneys and different value added products. Due to its exotic flavour and medicinal property, it is used in the preparation of special foods, beverages and pharmaceutical and cosmetic products. It has a long history of

traditional uses ranging from folk medicine to several culinary preparations. It has antibacterial, insecticidal, antifungal and antioxidant properties (Shankaracharya, 1982; Nadkarni, 2005; Jatoi *et al*., 2007; Policegoudra and Aradhya, 2008).

Kaempferia galanga L. is a geophilous aromatic perennial herb with very fragrant rhizomes and ovoid to spherical white tubers at the tips of fibrous roots. Leafy stem is short or absent, flowers few to many, spirally arranged, produced singly in the axils of bracts (Sivarajan and Balachandran, 1994; Sabu, 2006). The plant is known as aromatic ginger, sand ginger or resurrection lily. It is also known as galangal. In Sanskrit it is known as *chandramulika* or *sugandhavacha* and in Malayalam as *kacholam*.

The rhizome is stomachic, anti inflammatory and used for dyspepsia, headache and malaria. It is used by people of many regions for relieving tooth ache, abdominal pain and rheumatism (Ridtitid *et al.*, 2008). The aromatic oil is used as condiment and as a folk medicine. Asians employ the rhizomes and leaves as a perfume in cosmetics and also as an insecticide (Anonymous, 2007).

Studies on both the species with an objective of assessing their genetic variability and genetics of agronomic characters have been attempted only to a limited extent. The present experiments have been designed with the objective of analyzing the genetic variability, character association and genetic divergence of *Curcuma amada* Roxb. and *Kaempferia galanga* L. based on accessions collected from Kerala state of India so as to generate additional information and also to identify the best performing genotypes from them. A comparative study of the performance of the plants based on the status of planting material has also been designed so as to analyze the role of the status of the planting material in crop

production. Study of rhizome branching in both the species has also been carried out so as to bring out the peculiarities in rhizome branching pattern.

Chapter II

REVIEW OF LITERATURE

2.1. The family Zingiberaceae

The family Zingiberaceae is the largest family of Zingiberales and is one of the ten largest monocotyledonous families in India. It occurs chiefly in the tropics with about 52 genera and 1400 species with the greatest concentration in the Indo-Malayan region of Asia and represented by 22 genera and 178 species in India according to Jain and Prakash (1995). The family consists of 53 genera and 1200 species according to Kress *et al*. (2002). There are 9 genera and 70 species in South India (Sabu, 2006).

The Zingiberaceous plants are annual or perennial rhizomatous herbs. True aerial stem with nodes and internodes are present in genera such as *Alpinia, Amomum, Elettaria*, *Globba*, *Hedychium* and *Zingiber*. True stem is present or very short in *Curcumorpha*, *Kaempferia*, *Scaphochlamys* and *Stahilanthus* or a pseudo stem is formed by clasping leaf sheaths as in *Curcuma*, *Cyphostigma, Hitchenia, Paracautleya* and *Roscoea* (Nair, 1997; Sabu, 2006).

The rhizome may be short or long and interconnected rhizomes form a series known as sympodium meaning ‘jointed feet’ in Greek (Larsen *et al*., 1999). Shah and Raju (1975) noticed that sessile tubers of *Curcuma amada* and *Curcuma longa* show various geotropic responses. The apices which produce sheath leaves or foliage leaves show negative geotropism and apices with only scale leaves show positive geotropism.

Roots are fleshy or fibrous, long or short, terminating in some as fleshy tubers. The leaves exhibit a variety of morphological variations in structure, shape, size, texture and venation pattern. The colour of the leaves also shows much variation among different taxa. Leaves are sessile or petiolate and petiole length varies considerably. Often leaves have a sheath below, either encircling the stem or they themselves forming a pseudo stem. Ligule is present in the upper end margin of the sheath. Venation is generally pinnate to parallel with a prominent mid vein (Sabu, 2006).

The inflorescences are terminal, lateral or both terminal and lateral on the plant in different seasons. They are produced on the terminal part of the leafy shoot or from the base of the leafy shoot or on a special leafless branch directly from the rhizome. It may be a bracteate spike, raceme or panicle. Bracts are spirally arranged and the main bract is the primary bract or the fertile bract and the secondary bracts are called bracteoles. In *Curcuma,* the bracts are fused about their $^{1}/_{3}$ or ½ to form a pouch. In some species white or attractively coloured sterile bracts called comma bracts are present at the tip of the inflorescence. In *Kaempferia,* there is only one flower in the axil of each primary bract (Nair, 1997; Sabu, 2006).

Flowers are bisexual, irregular, zygomorphic, trimerous, dichlamydeous and epigynous. Calyx is tubular, three lobed at apex, sometimes splitting deeply on one side. Petals are three in number and are fused at the base to form a corolla tube, mostly unequal in size and usually with a hood as in *Curcuma.* The colour of corolla varies from white to yellow, orange, pink or purple. Androecium is derived from two trimerous whorls but usually one functional stamen is present in the family and it is the posterior one of the inner whorl. Labellum or lip is the large and most conspicuous part of the flower. In most cases staminodes are attached to the corolla tube and the fertile anther bears appendages. Ovary is

inferior, usually trilocular with axile placentation and rarely bilocular or unilocular with parietal placentation. Style long, filiform, usually as long as the stamen and held within the filament below and between anther thecae and appendages above. The stigma is generally well expanded. Epigynous glands are present just above the ovary. Fruits are usually dry or fleshy capsules or berries and mostly dehiscent. The seeds are arillate with perisperm and endosperm (Fischer, 1928; Purseglove, 1975; Nair, 1997; Sabu, 2006).

2.2. Medicinal gingers

Zingiberaceae forms an important group with economic potential and many members of this family yield spices, dyes, perfumes and medicines and some are ornamental. Many of them are used in ayurvedic and other native systems of medicine.

Turmeric is known as ‘golden spice’ as well as ‘spice of life’ and has been used in India as a medicinal plant and has strong association with sociocultural life (Jain and Prakash, 1995; Ravindran, 2007).

The word ginger truly refers to the edible ginger of commerce known botanically as *Zingiber officinale* Roscoe. Ginger is also the common term for members of the ginger family (Larsen *et al*., 1999; Sabu and Skinner, 2005).

The presence of essential oils such as limonene, eugenol, pinene, geraniol, etc. in many Zingiberaceae species has made some of them important since the time of ancient Greeks (Larsen *et al*., 1999). The rhizomes of many of them are dietary agents and are also used in traditional medicine (Chirangini *et al*., 2004).

Alpinia calcarata Roscoe is a native of India, the rhizomes of which with sharp odour and pleasant taste are used in the form of infusion for fever,

rheumatism and catarrhal affections. The rhizomes also form a major ingredient of several ayurvedic preparations (Kirtikar and Basu, 1975).

Alpinia galanga (L) Sw. is known as greater galangal and is a perennial rhizomatous herb. The rhizome is antibacterial, antirheumatic, antidiabetic, aphrodisiac and carminative (Chatterjee and Pakrashi, 2001; Sabu, 2006). Khare (2007) has reported antispasmodic action for the oils of the species. He has also indicated the antiulcer activity of its roots which has been attributed to the antisecretory and cytoprotective properties of the plant.

Alpinia officinarum Hance. is a native of South China and the plant is a perennial herb with a raceme of showy flowers and ornamental foliage. This is the lesser galangal and the rhizome possesses aromatic spicy odour and pungent taste, like a mixture of pepper and ginger. It is used in cooking, in medicine, for flavouring liquors and to impart a pungent flavour to vinegar (Pandey, 2001).

Alpinia speciosa (Wendl.) K. Schum is the light galangal. Rhizomes are antiulcerative and spasmolytic (Khare, 2007).

Amomum subulatum Roxb. is known as Nepal cardamom and the dried leathery fruits resemble cardamom in aroma and flavour. In medicine it is used to correct digestive disorders and as an antivomiting drug. Large cardamom is used as preventive as well as curative for throat troubles, congestion of lungs, inflammation of eye lids, digestive disorders (Chatterjee and Pakrashi, 2001; Sabu, 2006).

Curcuma aeruginosa Roxb. is used for the extraction of East Indian arrow root or Travancore starch. It is used as a medicine for stomach disorders. The rhizome is aromatic with a blue colour in the centre which is variable depending on the nature of the soil and age of the rhizome. The rhizome is used for fever,

diarrhoea, swellings and skin diseases and its oil is antibacterial, antifungal and antihelmintic (Sabu, 2006; Khare, 2007).

Curcuma amada Roxb. is known as mango ginger. The rhizome is regarded as cooling and carminative and is useful in prurigo. The rhizomes are used externally in the form of paste as an application for bruises and skin diseases and combined with other medicines it is useful in improving quality of blood (Nadkarni, 2005). The paste is applied externally to bruises, sprains, contusions, rheumatic pains and black eye (Khory and Katrak, 1999).

Curcuma anguistifolia Roxb. is called East Indian arrow root. The rhizome is used as a source of arrow root which is largely manufactured and exported in Malabar. The tubers are used for the extraction of starch. It forms an important food of tribal people in the area. It is cooling, demulcent and nutritious and is used in dysentery, dysuria, typhoid, fevers and ulcerations (Nadkarni, 2005; Skornickova *et al*., 2007).

Curcuma aromatica Salisb. is known as wild turmeric or Cochin turmeric. Rhizomes are bitter, carminative, appetizer and tonic, and are used in combinations with astringents and aromatics for bruises, sprains, bronchitis, cough, leucoderma and skin eruptions. Dried rhizome is used as an aromatic adjunct to other medicines used in skin diseases and impurities of blood. Boiled in oil, it is applied externally as an application to sprains and bruises (Warrier *et al*., 1994; Joshi, 2000; Nadkarni, 2005).

Curcuma caesia Roxb. is a species with blue rhizome and is commonly called black turmeric. The leaf has a deep violet patch which runs throughout the lamina. Rhizome is aromatic, carminative and stimulant and a paste made from the rhizome is used to cure dysentery and as poultice in rheumatic pain, sprains and bruises (Chatterjee and Pakrashi, 2001; Ravindran, 2007).

Curcuma longa L., commonly called turmeric occupies an important position and forms an integral part of the rituals, ceremonies and cuisine. Ethnobotanical evidences indicate that the use of turmeric has begun in ancient times related with worship, magical rites, colouring matter, medicine and spice. The rhizome has antiseptic, aromatic, alterative, antipyretic, germicidal, carminative, stimulant, tonic and vermifuge properties. The drug cures diseases due to morbid *vata*, *pitha* and *kapha*. It is used in diabetes, eye diseases, ulcers, oedema, anaemia, anorexia, leprosy and scrofula (Sivarajan and Balachandran, 1994; Velayudhan *et al*., 1999).

Curcumin has a protective effect on intestine and liver. The anticancerous effect of curcumin is mainly due to induction of apoptosis and inhibition of cell cycle (Chen and Huang, 1998). Recent studies have revealed that *Curcuma longa* could be the source of a new drug molecule to combat Alzheimer's disease by protecting the brain cells from β-amyloid insult (Park and Kim, 2002).

The antioxidant activity of curcumin is important directly as a biomedical compound and also as a food additive to prevent oxidation and resultant rancidity of oils and fats during storage (Sharma, 1976; Khanna, 1999). Turmeric reduces high plasma cholesterol and its antiplatelet activity offers protection to heart and vessels and also it prevents DNA damage in lymphocytes. The rhizome gives curcuminoids and the mixture is known as curcumin which is related to phenolics and possesses antioxidant, anti-inflammatory, gastroprotective and hepatoprotective activities. Curlone obtained from the dried rhizomes is used against hepatitis (Khare, 2007). Turmeric plays important role in traditional veterinary medicine (Sasikumar, 2005).

Curcuma mangga Valeton and Zijp. is called white turmeric and is popular in Central Java and the surrounding areas. The plant is closely related to turmeric but the rhizomes are similar to ginger and with raw mango taste. Due to this it is used in pickles. The rhizome is light yellow and is used for curing fevers and abdominal pain (Skornickova *et al*., 2007; Anonymous, 2009a).

Curcuma zanthorrhiza Roxb. is employed in ayurvedic medicines as a stomachic and is also applied to bruises and sprains. In colds, a decoction of the rhizome with long pepper, cinnamon and honey is reported to be good (Sabu, 2006). The species got its specific epithet from the deep yellow orange colour of its rhizomes which are medicinally valued especially in Malaysia and Indonesia (Ravindran *et al*, 2007). It is used to cure skin diseases, gall stones and diseases of digestive and urinary systems (Skornickova *et al*., 2007).

Curcuma zedoaria (Christm) Roscoe is found in wild as well as under cultivation all over India and Bangladesh and is reported from most other Asian countries. The rhizome is used in ayurvedic and unani medicines as antihelmintic, antipyretic, alexiteric, expectorant and carminative. The rhizome is employed as stomachic and is also applied to bruises and sprains. The root is an ingredient in some of the strengthening conserves taken by women after child birth (Kirtikar and Basu, 1975; Skornickova *et al.*, 2007).

Elettaria cardamomum (L) Maton is a perennial herb with thick horizontal root stock. It is known as the queen of spices. The seeds are used as condiment and medicinally. Cardamom has stimulant properties and is used as a spice and masticator. Seeds are useful in asthma, bronchitis, cardiac disorders, anorexia, dyspepsia, gastropathy, debility and vitiated condition of *vata*. Cardamom oil is used in several pharmaceutical preparations (Fischer, 1928; Warrier *et al.*, 1994; Joshi, 2000).

Hedychium coronarium Koenig, is a stout perennial herb commonly grown as ornamental. The rhizome is considered antirheumatic and excitant. The rhizome and leaf paste are applied for headache. The essential oil from rhizome shows anthelmintic and mild tranquilizing property. Among the tribal inhabitants of Orissa, a paste from the essential flowers and black pepper is taken orally, used for dysuria (Parrotta, 2001; Khare, 2007).

Hedychium spicatum Ham ex Smith, the spiked ginger lily and is a rhizomatous perennial tuberous herb. Rhizome is used in dyspepsia and as carminative, stimulant, stomachic and tonic (Joshi, 2000; Chatterjee and Pakrashi, 2001; Sabu, 2006).

Kaempferia galanga L. rhizome is stomachic and anti-inflammatory. In the form of powder or ointment it is applied to wounds and bruises to reduce swellings. They improve complexion and cure burning sensations, mental disorders and insomnia. Decoction of rhizome is used for dyspepsia, head ache and malaria. Roasted rhizomes are applied hot in rheumatism and for hastening the ripening of inflammatory tumors. Leaves are used in lotions and poultices for sore eyes, sore throat, swellings, rheumatism and fevers. The tuber powdered and mixed with honey is prescribed for coughs, asthma and pectoral affections (Joshi, 2000; Nadkarni, 2005).

Kaempferia rotunda L. is an erect herb with tuberous rhizomes. The whole plant is useful in the form of powder or ointment as an application to wounds and bruises to reduce swellings. The powder extracted from *Kaempferia rotunda* is made into ointment and is used for healing fresh wounds. It is taken internally to remove coagulated blood or purulent matter and is used in many ayurvedic preparations. The tubers are useful in vitiated condition of *vata* and

kapha, gastropathy, dropsy, inflammations, wounds, ulcers, blood clots, tumours and cancerous swellings (Warrier *et al*., 1995; Singh and Panda, 2005; Sabu, 2006).

Zingiber mioga Roscoe, the Myoga ginger or Japanese ginger is a perennial woodland species, endemic to Japan. There it is used as a substitute for true ginger. In Chinese Pharmacopoeia, myoga ginger is suggested to treat fever and also as a vermifuge (Sabu and Skinner, 2005).

Zingiber montanum (K.D.Koenig) Link ex Dietr., the wild ginger or forest ginger is native to India. The rhizome is used in diabetes. The tribals use the rhizome as a substitute for *Curcuma longa* and is an ingredient of many traditional medicines (Sabu and Skinner, 2005; Sabu, 2006).

Zingiber officinale Roscoe is a perennial herb and is one of the reputed drugs employed in indigenous systems of medicine. Both fresh rhizome and dried rhizome are used in medicine (Sivarajan and Balachandran, 1994). In ancient India, ginger was not significant as a spice, but it was called *mahabheshaj* or *mahaoushadhi* meaning the great cure and used in medicine (Ravindran and Nirmal Babu, 2005). The rhizome possesses stimulant, aromatic and carminative properties when taken internally and when chewed it acts as a sialagogue. Externally it is applied as rubefacient. It is anti rheumatic, carminative, diuretic and aphrodisiac. It promotes digestive power, cleans the throat and tongue, dispels cardiac disorders and cures vomiting (Sivarajan and Balachandran, 1994; Joshi, 2000).

The rhizome of ginger yields an essential oil which lacks the pungent principle and is used in the manufacture of flavouring essences and in perfumery. An oleoresin is extracted in which the full pungency of the spice is preserved and

is used medicinally. Gingerol and shogaol have been shown to suppress gastric contractions. They have gained importance due to their sedative, anti-inflammatory, antipyretic, analgesic and hepatoprotective activities. Antimigraine effect of ginger is due to its ability to decrease platelet aggregation (Purseglove, 1975; Khare, 2007).

Zingiber spectabilis Griff., known as bee hive ginger due to the peculiar shape of the spike, is widely used in Malayan traditional medicine (Burkill and Haniff, 1930).

Zingiber zerumbet (L) Smith, a native of tropical Asia is known as shampoo ginger or pine cone ginger. The inflorescence releases a thick juice when squeezed and is used to make Paul Mitchel and Freeman's shampoo (Sabu and Skinner, 2005). Rhizome is useful in colic, head ache, haemorrhoids, respiratory disorders, cough, asthma, leprosy and skin diseases (Chatterjee and Pakrashi, 2001; Khare, 2007).

The information presented above provides a bird's eye view of the diversity and uses of the members of the family Zingiberaceae. *Curcuma amada* Roxb. (English: mango ginger; Sanskrit: k*arpuraharidra* and *amragandha*) and *Kaempferia galanga* L. (English: galangal, sand ginger, aromatic ginger, resurrection lily; Sanskrit: c*handramulika* and *sugandhavacha*) are two potentially important members of the family. The literature available on these two species is presented below under appropriate heads.

2.3. *Curcuma amada* Roxb.

Curcuma L. is the largest genus of the tribe Hedychieae of the family Zingiberaceae. The name of this genus most probably originated from the Arabic word *kurkum* which means yellow and corresponds with the colour of the

rhizomes and flowers (Nayar, 1985; Skornickova and Sabu, 2002). The genus consists of around 120 species distributed from tropical Asia to Australia and South Pacific (Skornickova *et al*., 2004). Many forms are cultivated. Some of them did not flower usually or flower very irregularly. Some of them are polyploids (Skornickova and Sabu, 2002). Considering the great diversity of the genus represented by over 80 species in the Indo-Malayan region, it is considered that the genus originated in this region. The fact that over 40 species of the genus are indigenous to this country is more supportive to the concept of its Indian origin (Velayudhan *et al*., 1999).

Curcuma amada Roxb. is known as mango ginger in English, *karpuraharidra* in Sanskrit and *amada* in Bengali. In Malayalam it is called *manga inchi*. The plant is a rhizomatous herb with palmate and sessile tubers united to the sides of an ovate conic bud which gives rise to the leaves and spikes. The name of the species came from the peculiar smell of the rhizome, that of unripe mango. It grows well in fertile soil with free drainage (Saji and Sasikumar, 2004; Sabu, 2006).

The rhizome is light yellow inside, white towards the periphery with sessile thick fingers which are cylindric, ellipsoid, branched and horizontal. Roots are fleshy and root tubers absent. Leaves are oblong, petiolate, lanceolate, acuminate, pinnately veined, lower surface puberulous, upper glabrous, tip hairy; inflorescence is lateral or central, spike long, comma bract fused at the base, spreading light violet or pink fertile bracts fused to form a green pouch. Flowers are large, 4-5 in each bract. Calyx is deeply cleft on one side, 3-lobed at the tip. Corolla tube is funnel shaped, lobes unequal, dorsal lobe larger; labellum is elliptic, 3-lobed; lateral staminodes pale yellow; stamen white, basal spur 1 mm long, slightly convergent, glabrous; epigynous glands two; ovary inferior, trigonous, tricarpellary, syncarpous with many ovules on axile placentum. Style is

long, filiform, stigma closely appressed within the anther lobes. Fruit setting is not seen (Fischer, 1928; Sabu, 2006). The plant resembles *Curcuma longa* in morphological characters but can be distinguished by the cream coloured rhizome with the taste of fresh mango coupled with ginger flavour (Jayachandran and Nizam, 1997; Saji and Sasikumar, 2004).

2.3.1. Agronomy

The cultivation practice of mango ginger is almost similar to that of turmeric. Planting is generally done during May-June in India. Disease free rhizome fingers are used as planting material. Field beds of desirable size are prepared and farm yard manure or well decayed compost is added. After planting the rhizome, the beds are mulched with green leaves. Rhizomes germinate within 3–4 weeks. Weeds are removed and mulching repeated after 50 days. Harvesting the crop starts from October and continues up to January (Anonymous, 2003a; Saji and Sasikumar, 2004).

The crop comes up well in open conditions, but tolerates low level of shade and therefore partially shaded situations can also be utilized for cultivation. It can be well accommodated as an intercrop in coconut gardens and in rotation with other crops and also as a crop component in homesteads (Anonymous, 2007).

A study of the role of NPK nutrition on the growth and yield of mango ginger showed that NP, NK and NPK interaction effects were significant on yield. NPK at 30:30:60 kg/ha produced maximum yield followed closely by NPK at 30:45:60 kg/ha and NPK at 45:30:60 kg/ha (Mridula and Jayachandran, 1998; 2001).

Jayachandran and Nair (1998) found that rhizome yields under open and 25% shaded conditions were similar indicating that the crop was shade tolerant and suitable for intercropping situations. Jayachandran and Mridula (1998) found that 1500 – 2000 kg planting material is required per hectare and an average yield of 25 – 30 tonnes per hectare is obtained.

Hegde *et al*. (2006) studied the effects of row spacing on the performance of *Curcuma amada* and found that wider spacing resulted in the highest number of tillers, leaves, mother fingers, primary fingers and secondary fingers and closer spacing registered the highest leaf area index and fresh rhizome yield.

Compared to related crops like ginger and turmeric, mango ginger is free from pests and diseases. The attack of the shot borer *Conogethes punctiferalis* has been reported and it can be controlled by pulling out the dead hearts with larvae and burning it. Spray of 0.05% dimethoate or quinalphos is also recommended (Anonymous, 2007).

2.3.2. Morphology

Shah and Raju (1975) have described the growth pattern of the rhizomes of mango ginger. The main axis that develops from the seed rhizome appears bulbous at an early stage. It produces primary branches from the lower node. During early period of growth, they show diageotropic, positive geotropic and oblique growth. The primary branches ultimately show negatively geotropic response at their extreme tips. In many cases a pair of primary branches of the opposite side of the main axis shows similar response. The negative geotropic growth is correlated with the formation of sheath leaves and foliage leaves, and those which form only scale leaves grow in various directions. The secondary branches show positive geotropic growth from the lower side of the horizontally growing primary branch.

Jayachandran (1993) studied rooting pattern of mango ginger. He observed that immediately after planting, the viable vegetative bud present on the seed rhizome starts developing and mother rhizome is formed. This forms the first tiller and from the mother rhizome primary finger rhizomes are produced which in turn produce secondary rhizomes and the process is continued. A second or third mother rhizome is produced depending upon the intensity of the vegetative growth. Roots are mainly developed from the mother rhizome and some roots are produced from the finger rhizomes. The three types of roots observed are succulent, thin and hairy. Succulent roots are fleshy at the base and thinner towards the tip, thin roots are more in number and hairy roots arise from succulent and thin roots. 74.3% of the total roots are confined to the top layer of soil indicating the suitability of the crop as an intercrop.

2.3.3. Anatomy

Comparative rhizome anatomy of four species of *Curcuma* has been studied by Sherlija *et al*. (1998). They found that though they were basically similar in structure, some variation existed between the species. The number and arrangement of vascular bundles, orientation of endodermal layers, number and shape of starch grains and curcumin cells varied.

Anatomical and histochemical studies of four species of *Curcuma*, namely C.*longa*, C.*aromatica*, C.*amada* and C.*zedoaria* by Remashree and Balachandran (2006) showed that though all the species had basically similar anatomical characters, they varied in the number and arrangement of primary and secondary bundles, orientation of tissues, number and shape of curcumin cells, starch grains and oil cells. The starch grains were medium sized, oval with angular edges and number of curcumin cells was only few in *Curcuma amada* compared to other species.

2.3.4. Embryology

Many *Curcuma* species do not set seeds and are propagated vegetatively by rhizome branches (Skornickova *et al*., 2004). According to Sabu (2006) seed setting is not seen in *Curcuma amada.*

2.3.5. Cytology

In the genus *Curcuma*, the following chromosome numbers are met with. In *Curcuma aromatica* and *Curcuma amada* 2n= 42 and in *Curcuma longa* 2n= 62. The species of *Curcuma* with 42 chromosomes are believed to be amphidiploids derived from a cross between 12 and 9 chromosomed ancestors. Thus in the course of evolution of the different species, polyploidy seems to have played an important role in the genus (Raghavan and Venkatasubban, 1943). Treatment with ethyl methane sulphonate showed cytological irregularities in the growing root tip cells of *Curcuma amada* (Datta and Biswas, 1985). Das *et al*. (1998) observed positive correlation between the genomic chromosome length, chromosome volume and interphase nuclear volume in members of Zingiberaceae including *Curcuma amada*.

2.3.6. Phytochemistry

According to Shankaracharya (1982), the yield of essential oils of mango ginger is about 0.1% on fresh weight basis or 0.7% on dry weight basis and the oil is highly aromatic. The oleoresin obtained lacks the pungency of true ginger. On fresh weight basis, the composition of mango ginger is moisture 86 g; starch 6.9 g; total sugar 0.82 g; traces of reducing sugars; crude fibre 1.49 g; essential oil 0.1 ml per 100g; and total ash 0.803 g. On dry weight basis, the values are starch 45.64 g; total sugar 5.86 g; traces of reducing sugars; crude fibre 10.63 g; total ether extractives 6.55 g; alcohol solubles 16.69 g; ash 5.746 g and essential oil 0.93ml per 100gm. A curcumin content of 0.1% has been reported in *Curcuma*

amada (Anonymous, 2009c). However, it is very low when compared with the curcumin content of *Curcuma longa* which reaches as high as 7% in some varieties (Premavalli, 2007).

Gholap and Bandyopadhyay (1984) found that essential oil of *Curcuma amada* rhizome was primarily composed of terpene hydrocarbons identified as alpha-pinene, car-3-ene and cis-ocimene and the last two compounds were responsible for the characteristic mango odour.

Srivastava *et al*. (2001) analysed the essential oil of *Curcuma amada* and twenty eight constituents were identified. The major compounds were ar-curcumene (28.1%), beta-curcumene (11.2%), camphor (11.2%), curzerenone (7.1%) and 1, 8-cineole (6.0%). Saji and Sasikumar (2004) found that steam distillation of dried rhizomes of *Curcuma amada* gave 1.1% volatile oil which constituted d-u-pinene, ocimene, linalool, linalyl acetate and safrole.

Policegoudra *et al*. (2007a) investigated the accumulation of bioactive compounds and storage components during developmental stages of mango ginger rhizome. Four developmental phases were defined namely, vegetative phase (60 days from planting), initiation and development phase (60–150 days), maturation phase (150–180 days) and senescence phase (180 days). Difurocumenonol and phenolics were identified as biomarkers. Difurocumenonol was observed 120 days after planting and its peak accumulation along with phenolics and total protein was noticed in 180 day old rhizome. Based on that a harvest stage at 180 days rather than at 240 days has been suggested.

Isolation and characterization of starch from mango ginger has been reported by Policegoudra and Aradhya (2008). It was characterized with respect to amylase solubility, gelatinization, ash, moisture content, X-ray diffraction

pattern and structure of starch granules. Mango ginger contains 1.3% ash, 9.8% moisture and 45% starch with 43% amylase. The shape of the granule appeared as round, elliptic, irregular and polygonal. The granule size varied from 3–20 µm to 20–48 µm. X-ray diffractogram revealed B-type of starch, characteristic of *Curcuma* sp. and majority of tuber starch in contrast with C-type pattern of ginger. Low solubility accompanied with high amylase content of mango ginger starch can be a metabolic advantage.

More than 130 chemical constituents with biomedical significance have been isolated from mango ginger according to Jatoi *et al*. (2007).

2.3.7. Biotechnology

Barthakur and Bordoloi (1992) have developed a protocol for cultivation and conservation of *Curcuma amada*. They found that rhizome explants produced shoots and roots simultaneously when cultured on B5 medium containing NAA (0.5mg/litre) and BA (4mg/litre).

Prakash *et al*. (2004) outlined a protocol for direct and indirect regeneration of *Curcuma amada* using rhizome and leaf sheath explants. Multiple shoots were obtained from rhizome explants in Murashige and Skoog medium fortified with 4.44 µM BA and 1.08 µM alpha naphthalene acetic acid (NAA). For indirect regeneration, semifriable callus obtained from leaf sheath explants on MS medium with 9.0 µM 2, 4-D was used.

2.3.8. Crop improvement

In Kerala, local varieties are used for cultivation. ‘Amba’, a germplasm selection is an improved variety of mango ginger released from High Altitude Research Station, Orissa University of Agriculture and Technology (OUAT), Pottangi, Orissa. It is a selection from local germplasm with an average yield of

28 t/ha of fresh rhizomes. The variety has an oleoresin content of 6.48%, essential oil content of 0.8%, curcumin content of 0.1% and dry recovery of 18.7%. The variety is free from pests and diseases (Johny and Ravindran, 2005; Anonymous, 2009c). This is the only variety of this crop reported from India. Mango ginger types differing in rhizome morphology are seen in the country (Saji and Sasikumar, 2004; Anonymous, 2007).

Moharana *et al*. (2008) observed difference in morphology and rhizome characters including yield when different genotypes of mango ginger collected from different agroclimatic zones of India like West Bengal, Orissa and Kerala were analyzed.

2.3.9. Economic importance

Mango ginger has got a reputed position as a traditional medicinal herb. The rhizome finds extensive use in indigenous systems of medicine. It is cooling and useful in prurigo. Ayurveda has highlighted the importance of this rhizome as an appetizer, antirheumatic, diuretic, aphrodisiac and astringent. It promotes digestive power, cleans throat and tongue, dispels cardiac disorders and cures vomiting, anaemia and cough. It has specific action in rheumatism and inflammation of liver. It is applied externally as paste for bruises and skin diseases. It is used as one of the ingredients of rasayanas and a number of carminative and digestive churnas. Clinical trials prove that it reduces serum cholesterol level in hypercholesterolemic rats (Kirtikar and Basu, 1975; Joshi, 2000; Saji and Sasikumar, 2004).

Srinivasan and Chandrasekhara (1992; 1993) studied the effect of mango ginger on lipid status in normal and hypertriglyceridimic rats and observed that *Curcuma amada* reduced liver total lipids and free fatty acids on the standard diet and decreased liver weight and serum total lipids on the high sucrose diet. The

extract of *Curcuma amada* rhizomes showed antiinflammatory and analgesic activity in acute and chronic administration in albino rats (Mujumdar *et al*., 2000; 2004).

Chirangini *et al*. (2004) studied the antioxidant properties of selected medicinal Zingiberales including *Curcuma amada* and revealed the potential medicinal use of the rhizomes as dietary agents. Shankaracharya (1982) reported the use of mango ginger as a food spice due to its mango flavour in the preparation of pickles, chutney, candy, preservatives, sauces and salads. Pushpalatha and Sheela (2003) also analysed the suitability of this spice for the preparation of value added products.

Policegoudra *et al*. (2007b) isolated a pure antioxidant compound 'amadannulen' from the rhizome of *Curcuma amada* which exhibited multisystem antioxidant activity and also antimicrobial activity. The antioxidant activity of amadannulen includes reductive ability, metal chelator, hydrogen donating ability and scavenging of superoxide radicals. Amadannulen also showed antibacterial and bactericidal activities.

Extracts of *Curcuma amada* rhizome proved fungitoxic with several species pathogenic to plants and animals. Activity differed according to source of rhizome and between seasons, being lowest in rhizomes of rainy season and highest in late winter and early summer (Ghosh *et al*., 1980). *Curcuma amada* natural oil from India is used as a pure natural aroma therapy oil (Anonymous, 2009b).

2.4. *Kaempferia galanga* L.

The genus *Kaempferia* L. includes about 70 species, about two third of which are found in Asia and remaining one third in Africa (Kam, 1980). The

genus comprises approximately of 60 species from tropical Africa to India and South East Asia (Sirirugsa, 1989). The generic name commemorates Engelbert Kaempfer (1651-1716), a German naturalist and physician (Nayar, 1985). From South India, three species have been reported: *Kaempferia galanga* L., *Kaempferia rotunda* L. and *Kaempferia scaposa* (Nimmo) Benth. and Hook. *Kaempferia galanga* L. and *Kaempferia rotunda* L. are aromatic herbs with a number of medicinal properties. *Kaempferia scaposa* (Nimmo) Benth. and Hook is a rhizomatous herb. *Kaempferia elegans* Wall. is an ornamental species from Malaysia, introduced and grown in gardens of South India and popularly called 'bronze peacock' or 'peacock ginger'. The feather pattern of the leaves is very attractive and the plants form a nice ground cover (Sabu, 2006).

Kaempferia galanga L. is known as *sugandhavacha* and *chandramulika* in Sanskrit and is used as spice, condiment, medicine and in cosmetics. It is a geophilous perennial herb with very fragrant white rhizomes and ovoid to spherical white tubers at the tips of fibrous roots. Leafy shoot is stem less and almost horizontal near the ground. Leaves 2 or 3, lamina 10-15 x 6-10 cm, broadly ovate or orbicular, base rounded to sub cordate, tip broadly pointed, upper surface dark green, white with violet tinge towards the tip, densely hairy, inflorescence sessile, 6-12 or more flowered, enclosed within leaf sheaths with one flower opening at a time. Leaves possess uniseriate non glandular trichomes. Bracts bifarious, outer larger, inner smaller, ovate, acuminate, white with light green tip, glabrous. Bracteoles split to the base, thus each flower appears to have two bracteoles. Calyx is equal or shorter than the bracts, glabrous, corolla tube long, lobes white, 3-lobed. Fertile stamen one, staminodes petaloid, tip deeply 2-lobed, ovary inferior, 3 celled, style filiform ending in a turbinate, urceolate stigma with epigynous glands. Fruit is a capsule. The plant is a native of India and cultivated throughout India, Malaysia, Africa, Java, China and Sri lanka. Now it is very rare in wild in South India (Sivarajan and Balachandran, 1994; Nadkarni,

2005; Sabu, 2006). According to Singh and Panda (2005) the plants are common in plains, low elevations, especially in shaded areas of the forests. The economic part is the rhizome and is propagated vegetatively using rhizome. The active ingredient of the rhizome is an essential oil (Rajagopalan and Gopalakrishnan, 1985b).

2.4.1. Agronomy

Kaempferia galanga L. requires fertile sandy soil and warm humid climate and it thrives well up to an elevation of about 1500 metres above MSL. A well distributed annual rainfall of 1500-3000 mm is required during the growth period. The species is propagated by rhizome with at least one healthy sprout. Rhizomes can be stored in cool dry places or pits dug under shade and plastered with mud or cow dung. Two weeks before planting of the new crop, smoking the rhizomes by spreading on *Glycosmis pentaphylla* leaves is practiced in certain localities (Ravindran and Balachandran, 2005; Anonymous, 2007).

Rajagopalan and Gopalakrishnan (1985a) studied the influence of planting time and type of seed material in the case of *Kaempferia galanga*. They found that the type of seed material did not show significant impact on the morphological characters but with respect to yield characters and oleoresin content, mother rhizome showed superiority over finger rhizome. Early planted crop was significantly superior to mid and late planted crops.

According to Maheswarappa *et al*. (1999a; 1999b; 2000a; 2000b; 2000c; 2001), growth and rhizome yield were higher when *Kaempferia galanga* was grown as an intercrop. Monocrop yielded 4.8 t/ha whereas intercrops yielded up to 6.1 t/ha. The essential oil and oleoresin contents were also higher in intercropped rhizomes. The highest number of rhizomes per plant, volume of rhizome and fresh rhizome yield were observed when mother rhizome was used

as the planting material. The chlorophyll and carotenoid contents did not differ significantly when mother and finger rhizomes were used as planting material. The numbers of tillers and leaves and leaf area produced with mother rhizome were significantly more at 120 and 180 days after planting compared to finger rhizome. They also observed that sprouting was not affected by the types of planting material or plant population levels and different organic manures.

Gunathilake *et al*. (2000) observed the feasibility of growing *Kaempferia galanga* under coconut plantations. Yield and chemical quality showed higher rate when compared to those grown in open field. Mulching with *Azadirachta indica*, *Chromolaena odorata* and *Gliricidia maculata* leaves gave the highest average fresh weights. The highest rhizome yield was obtained with *Azadirachta indica* mulches and was effective in nematode infection (Nisha and Sheela, 2002).

The performance of *Kaempferia galanga* ecotypes as influenced by variations in shade and preparatory cultivation was studied by Gangadharan and Menon (2003) and observed that high rhizome yield was correlated with high P, K and Ca contents, while high essential oil with high Mg, S, Mn and Zn contents in the rhizome. Rhizome yield was high at shallower tillage depth and higher light intensity, while essential oil yield was high at deeper tillage depth and lower light intensity. Low light intensity increased the biosynthesis of oleoresin and essential oils in the rhizomes as well as the contents of Ca, Mg, Mn and Zn.

Regarding the effect of different light transmission levels on the growth and yield of *Kaempferia galanga*, Kumar *et al*. (2005) observed that the presence or absence of overhead canopy cover seemed to have little effect on rhizome yield as yield responses under no over canopy, single strata and multi strata systems were similar. Rhizome quality did not exhibit any remarkable trends with respect to canopy structure.

A well managed plantation of *Kaempferia galanga* yields about four to six tonnes of fresh rhizomes per hectare (Ravindran and Balachandran, 2005).

Narayanan *et al*. (2004) found that *Kaempferia galanga* shows high resistance to petroleum polluted environment and water stress.

Pseudomonas solanacearum is reported to cause bacterial wilt in *Kaempferia galanga* (Dake and Manoj, 1995). Priya *et al*. (2005) isolated three pathogens, *Colletotrichum gloeosporioides*, *Colletotrichum capsici* and *Pseudomonas solanacearum* from *Kaempferia galanga* and studied the antagonistic effect of *Trichoderma viride* and *Aspergillus niger* on them. For leaf rot disease, 1% Bordeaux mixture or 0.2% Thiram and for nematode diseases caused by *Meloidogyne incognita* and *Radopholus similis*, rhizome treatment with *Pseudomonas fluorescens* (Pfl) at 3% weight by weight of seed material or mulching with neem, *Chromolaena* or *Glyricida* at the rate of 5kg/m^2 at 30 DAP is recommended (Anonymous, 2007).

2.4.2. Cytology

There is difference of opinion regarding the chromosome number of *Kaempferia galanga*. Raghavan and Venkatasubban (1943) found that four species of *Kaempferia* showed a regular polyploid series 24, 36 and 54, all multiples of 6, which is considered the basic number of this genus. According to Sharma and Bhattacharya (1959) the normal somatic chromosome compliment of *Kaempferia galanga* has been determined to be 2n = 22. These are classified into three general groups as six pairs of long chromosomes, four pairs of medium sized and a pair of short chromosomes. The Asiatic species of *Kaempferia* show a preponderance of diploids (2n = 22), presumably derived from a basic x = 11; the African species however have either 2n = 28 or 2n = 42 with x = 14 as the

basic number (Spearing and Mahanty, 1964). Ramachandran (1969) is of opinion that *Kaempferia galanga* is presumably an aneuploid pentaploid since the root tip cells show 54 chromosomes.

2.4.3. Phytochemistry

Wong *et al*. (1992) investigated the essential oil of rhizome of *Kaempferia galanga* and fifty four components were identified. The major constituents were ethyl trans–p–methoxy cinnamate (51.6%), ethyl cinnamate (16.5%), pentadecane (9.0%), 1,8-cineole (5.7%), delta-car-3-ene (3.3%) and borneol (2.7%); terpenoid constituents amounted to 16.4%. The volatile oil content was higher in rhizome than in root (Arambewela *et al*., 2000).

According to Ravindran and Balachandran (2005) *Kaempferia galanga* rhizome contains 2.5 to 4% essential oil. The main components of the oil are ethyl cinnamate (25%), ethyl–p-methoxy cinnamate (30%), p-methoxy cinnamic acid and a monoterpene ketone compound, 3-carene-5-one. The other constituents are camphene, δ-3-carene, p-methoxy styrene, γ-pinene, β-myrcene, p-cymene, 1, 8-cineole, isomyrcene, camphor, γ-terpineol, p-cymene-8-ol, eucarvone, δ-cadinene etc. The leaves contain kaempferol, quercetin, cyanidin and delphinidin. The essential oil is used in flavouring curries, in perfumery and also for medicinal purposes. The oil yield varies with season and maturity stage of rhizome.

The major chemical components present in the volatile oil of *Kaempferia galanga* were identified by Tewtrakul *et al*. (2005) as ethyl-p-methoxy-cinnamate (31.77%), methyl cinnamate (23.23%), carvone (11.13%), eucalyptol (9.59%), and pentadecane (6.41%).

Othman *et al*. (2006) isolated a vasorelaxant active compound ethylcinnamate as colourless oil from the crude extract of *Kaempferia galanga*.

Ethyl-p-methoxycinnamic acid was also isolated as white needles which did not exhibited relaxant effect on rat aorta.

The essential oils from rhizomes of *Kaempferia galanga* contain n-pentadecane, ethyl-p-methoxy cinnamate, ethyl cinnamate, carene, camphene, borneol, p-methoxy styrene, p-methoxy cinnamate, p-methoxy-trans-cinnamic acid and cinnamaldehyde. Insecticidal activity is due to ethyl cinnamates. Ethyl-p-methoxy cinnamate shows monoamine oxidase inhibitor activity and a cytotoxic principle. Leaves and flowers exhibit antiphlogistic and vitamin P activity (Khare, 2007).

2.4.4. Biotechnology

Kaempferia galanga is an important medicinal plant facing threat of extinction. Since conventional breeding is difficult in this plant, various protocols for *in vitro* multiplication have been developed by different workers to improve conservation and propagation.

Vincent *et al.* (1992) developed embryogenic callus from rhizome explants of *Kaempferia galanga* with vegetative buds using MS medium supplemented with 0.1 mg BA per litre plus 1.0 mg 2,4-D per litre. Callus sub-cultured on MS medium supplemented with 0.1 mg BA per litre plus 1.0 mg NAA per litre produced embryoids which developed into plantlets which were acclimatized and subsequently transferred to the field.

Repeatable high efficiency single step *in vitro* protocols for rapid propagation were established for *Kaempferia galanga* on MS medium supplemented with 4 mg BA, 1 mg Kinetin and 1mg NAA per litre by Jose *et al.* (2002). Plants were also obtained through somatic embryogenesis in callus derived from rhizome bud explants of *Kaempferia galanga* (Lakshmi and Mythili,

2003). Rahman *et al*. (2004) also reported efficient plant regeneration through somatic embryogenesis from leaf base derived callus of *Kaempferia galanga* L. Microrhizomes and synthetic seeds of ginger, *Kaempferia* and turmeric can be utilized for disease free transport and germplasm exchange (Nirmal Babu *et al*., 2007). Geetha *et al*. (1997) has developed a protocol for micropropagation of *Kaempferia galanga* and *Kaempferia rotunda*. Chirangini *et al*. (2005) observed that rhizomatous buds of *Kaempferia galanga* developed microshoots when cultured on MS medium supplemented with plant growth regulators.

Swapna *et al*. (2004) cultured leaf and rhizome explants of *Kaempferia galanga* aseptically on MS medium with various combinations of IAA, benzyl adenine, NAA, 2,4-D and kinetin at concentrations ranging from 0.5 to 2.5 mg/litre.

Chitra *et al*. (2005) developed a protocol for best rhizome development in *Kaempferia galanga*. MS medium with 8.87 µM benzyladenine (BA) and 2.46 µM indole-3-butyric acid (IBA) supplemented with 11.7 µM Silver nitrate facilitated the highest number of shoots and roots. Increase of sucrose concentration in the medium favoured the best rhizome development.

2.4.5. Crop improvement

Two high yielding varieties of *Kaempferia galanga*, Kasthuri and Rajani, with high yield potential and rich flavour have been developed by a team of scientists of Kerala Agricultural University through clonal selection. The rhizomes of the variety Kasthuri are large and light brown with a yield of 2.52 tonnes of dry rhizomes per hectare with a driage of 32.78%. Kasthuri has high volatile oil content and total extractive of 3.4%. The rhizomes of Rajani are medium bold and creamy white in colour and it yields 2.55 tonnes of dry rhizomes per hectare. Rajani goes well for medicinal purposes with a volatile

content of 1% with high total extractives of 7.68% (Anonymous, 2003b; Ravindran and Balachandran, 2005; Hali, 2006).

Indrayan *et al*. (2007) observed that Kasthuri and Rajani differ morphologically and biochemically. A total number of 58 and 56 compounds have been identified in Kasthuri and Rajani respectively. 45 compounds have been found common in both the oils and the major component was ethyl-trans-p-methoxy cinnamate.

Mutagenesis may have potential for increasing the genetic variability of *Kaempferia galanga*. Rhizome pieces possessing 1-2 viable buds were irradiated with gamma radiation to observe the dose inhibiting sprouting of rhizomes and its effect on yield factors. Low doses of radiation increased leaf number, leaf area and rhizome yield per plant and promoted flowering and in higher doses sprouting was inhibited (Kurian *et al*., 1993). Bushy type mutants were noticed with gamma irradiation and at lower doses below 1 kR. stimulatory effect in germination of rhizomes was produced (Ravindran and Balachandran, 2005).

2.4.6. Economic importance

In Rheede's Hortus Malabaricus, *Kaempferia galanga* L. has been described under the name *katsjula kelengu* which shows that the plant was used as a drug source in Kerala in the 17th century (Manilal, 2003). *Kaempferia galanga* is cultivated for aromatic rhizomes and also as an ornamental. It is used as a spice and has a long history of medicinal uses. The tubers and whole plant are bitter and camphoraceous. The small globular tubers are used as local application to tumors and glandular swellings of all kinds. An ointment of the whole plant is applied to fresh wounds. It is given internally in cases of pyaemia with an idea of removing blood or pus from the body. The rhizomes are considered stimulatory, expectorant, carminative and diuretic. In Philippines, a decoction of the rhizome

is used for dyspepsia, headache and malaria. The rhizomes and roots are used for flavouring food and medicine in South East Asia. The rhizome mixed with oil is applied to rheumatic regions. The powdered rhizome mixed with honey is an expectorant. It is used for heart diseases, treatment of abdominal pain, vomiting, diarrhoea and tooth ache with the function of promoting vital energy circulation and alleviating pain. *Kaempferia* forms a component of over 59 ayurvedic medicines. It is used as a masticator along with betel leaf and arecanut. A lotion prepared from the rhizome is used to remove dandruff or scales from the head. Water extract of dried rhizomes exhibits antitumour activity (Kirtikar and Basu, 1975; Khory and Katrak, 1999; Ravindran and Balachandran, 2005).

The rhizomes of *Kaempferia galanga* are widely used in traditional medicine and for food flavouring in Malaysia (Wong *et al*., 1992). According to Seidemann (1992), the leaves and rhizomes are used as a seasoning for savoury dishes and the rhizomes are used in East Asia for a wide range of medicinal applications.

Kaempferia galanga is used in Malay folk medicine against rheumatism, asthma and hypertension and the chloroform extract showed inhibitory effects on the vascular smooth muscle contraction of the rat aorta (Mustafa *et al*, 1996).

The rhizome is a constituent of a wide variety of ayurvedic preparations like *valiya rasnadi kashayam*, *asana eladi tailam*, *rasnachandanadi* tailam, *vacha tailam*, *kacholadi tailam*, *valiya narayana tailam*, *kachuradi churnam*, *panchagandhaka churnam* and *chyavana prasam* (Sivarajan and Balachandran, 1994; Thirumulpad, 2004).

Othman *et al*. (2002) isolated ethyl cinnamate from the rhizomes of *Kaempferia galanga* and examined its vasorelaxant effect on rat aorta. This effect

of ethyl cinnamate may explain the traditional use of the parent plant in treating hypertension. The oil obtained from the plant is used in food, local medicine and as a spice.

Larvicidal principles obtained from the methanol extract of *Kaempferia galanga* were identified as ethyl cinnamate, ethyl-p-methoxy cinnamate and p-methoxy cinnamic acid (Kiuchi *et al.*, 1988). The essential oils of *Kaempferia galanga* roots and rhizomes showed antibacterial acivity against *Escherichia coli* and *Staphylococcus aureus* (Arambewela *et al.*, 1999). Jantan *et al.* (2003) reported that the essential oil of *Kaempferia galanga* showed selective toxicity against *Aspergillus fumigatus*.

Vimala *et al*. (1999) found that the rhizomes possess inhibitory activity towards TPA (12-0-tetradecanoyl phorbol-13-acetate) induced EBV-EA (Epstein-Barr Virus-Early Antigen) activation in Raji cells.

In Malaysia, the leaves of *Kaempferia galanga* called *cekur* are familiar in *perutikan,* a local favorite dish (Larsen *et al*., 1999). The leaves and rhizomes are used in cosmetics and herbal powders (Hali, 2006). The plant is used in aroma therapy and forms one of the ingredients in pain relief ayurvedic massage blends (Huang *et al*., 2008).

The above review of the literature available on *Curcuma amada* Roxb. and *Kaempferia galanga* L. provides a general information on the species and it also indicates the importance of further studies on them. The present experiments have been designed based on it so as to study the genetic variability, interrelationship of characters, character association and genetic divergence of these species and also to select superior genotypes from the accessions collected for the purpose.

Chapter III

MATERIALS AND METHODS

Zingiberaceae is a treasure house of food, medicinal and ornamental plants. The present experiments have been designed to study the genetic variability and divergence of two species of the family, namely *Curcuma amada* Roxb. and *Kaempferia galanga* L. which are important for their medicinal and allied values. An effort has also been made to select superior genotypes from the accessions collected for the purpose, based on their overall performance. An experiment has also been carried out to study the performance of plants raised from rhizomes of different status. A study on rhizome branching in these two species has also been attempted.

3.1. The experimental site

The experiments were conducted in the experimental net house of the Genetics and Plant Breeding Division of the Department of Botany, University of Calicut, Kerala, India. The University of Calicut is located 23 km south of the historical city of Calicut located 75°45′ - 75°50′ E longitude and 11°25′ - 11°45′ N latitude at an elevation of 40 – 60 m from MSL.

The experimental area has got a tropical monsoon climate with south-west monsoon from June to August, north-east monsoon in October – November and dry spell from December to May with summer showers in March, April and May. Average temperature varies from 20°C to 30°C and annual rainfall is about 290 cm (Anonymous, 2008). The agricultural operations in the case of rain fed annual crops start in May and usually come to a close by November – December.

3.2. Experimental materials

Two species of the family Zingiberaceae, *Curcuma amada* Roxb.and *Kaempferia galanga* L. have been used for the present experiment.

3.2.1. *Curcuma amada* Roxb.

Curcuma amada Roxb. (mango ginger) is an underutilized member of the family Zingiberaceae. The plant is a rhizomatous herb with palmate and sessile tubers united to the sides of an ovate conical bud which gives rise to leaves and spikes (Saji and Sasikumar, 2004).

The rhizome of mango ginger is characterized by the smell of fresh unripe mango for which it has derived the specific epithet *amada* meaning mango ginger in Bengali. The rhizome is light yellow inside and white towards the periphery. The plant is related to *Curcuma longa* L. but can be distinguished from it by the characteristic smell of the rhizome and its pale colour (Sabu, 2006).

The plant is an aromatic herb with pseudostem 30-35 cm tall, leaves simple with sheathing leaf base, petiolate, oblong, lanceolate, acuminate and lamina of lower leaves smaller than the upper ones. Inflorescence is a lateral or central spike with distinct comma bracts, fused only at the base, spreading, light violet. Fertile bracts are green and fused to form a pouch. Calyx is short and 3-lobed. Corolla tube is funnel shaped with unequal lobes; labellum obscurely three lobed. Fertile stamen is single in number, style filiform, stigma closely appressed within the anther lobes. Ovary is tricarpellary, syncarpous with many ovules on axile placentum. Fruit setting is not seen (Sabu, 2006).

3.2.2. *Kaempferia galanga* L.

Kaempferia galanga L., a member of Zingiberaceae is useful in medicine, perfumery and also as a condiment. The plant is a rhizomatous herb with strongly

aromatic crowded rhizomes with numerous roots bearing white tubers. Leafy shoot is stem less, leaves only a few in number, lamina broadly ovate to orbicular, base rounded to subcordate, white with violetish tinge towards the tip. Inflorescence sessile, 6-12 in number, one flower opening at a time. Bracts are bifarious, bracteoles split to the base and thus each flower appears to have two bracteoles. Corolla lobes are white, labellum lobes white with violet bands at the basal half. Anther is white, stigma globular, ovary tricarpellary with many ovules on axile placentum (Sabu, 2006).

3.3. Experimental programmes

The experiments were conducted in the experimental net house of the Genetics and Plant Breeding Division of the Department of Botany, University of Calicut, Kerala, India during 2005-2007. The experiments were laid out in randomized block design with 3 replications. Fifty accessions of *Curcuma amada* Roxb. and *Kaempferia galanga* L. collected from different locations in the northern districts of Kerala have been used for the study (Tables 3.1 and 3.2 and Figs. 3.1, 3.2, 3.3 and 3.4).

Table 3.1. Accessions of *Curcuma amada* Roxb. studied

Sl No.	Accession No.	Source	District
1	CUM 1	Thrippalamunda	Palakkad
2	CUM 2	Kanjikulam	Palakkad
3	CUM 3	Kongad	Palakkad
4	CUM 4	Kanjirappuzha	Palakkad
5	CUM 5	Kalladikode	Palakkad
6	CUM 6	Karakurussi	Palakkad
7	CUM 7	Chittur	Palakkad
8	CUM 8	Pudunagaram	Palakkad
9	CUM 9	Alanallur	Palakkad
10	CUM 10	Kanjikkode	Palakkad
11	CUM 11	Muttikulangara	Palakkad
12	CUM 12	Ottappalam	Palakkad
13	CUM 13	Thachampara	Palakkad
14	CUM 14	Cherpalacheri	Palakkad

15	CUM 15	Pulapetta	Palakkad
16	CUM 16	Mundur	Palakkad
17	CUM 17	Karimba	Palakkad
18	CUM 18	Thuppanadu	Palakkad
19	CUM 19	Wayanad	Wayanad
20	CUM 20	Narikkuni	Kozhikode
21	CUM 21	Devagiri	Kozhikode
22	CUM 22	Kolathara	Kozhikode
23	CUM 23	Nallepulli	Palakkad
24	CUM 24	Chelavur	Kozhikode
25	CUM 25	Chathamangalam	Kozhikode
26	CUM 26	Kunnamangalam	Kozhikode
27	CUM 27	Perummanna	Kozhikode
28	CUM 28	Kottempram	Kozhikode
29	CUM 29	Sreekrishnapuram	Palakkad
30	CUM 30	Chenakkalangadi	Malappuram
31	CUM 31	Puthur	Palakkad
32	CUM 32	Kalpathy	Palakkad
33	CUM 33	Kodumbu	Palakkad
34	CUM 34	Valayar	Palakkad
35	CUM 35	Puduppariyaram	Palakkad
36	CUM 36	Yakkara	Palakkad
37	CUM 37	Vallikkode	Palakkad
38	CUM 38	Elapulli	Palakkad
39	CUM 39	Nemmini	Malappuram
40	CUM 40	Pandikkad	Malappuram
41	CUM 41	Ramanattukara	Malappuram
42	CUM 42	Cannanore	Cannanore
43	CUM 43	Manjeri	Malappuram
44	CUM 44	Nilambur	Malappuram
45	CUM 45	Vadakkanthara	Palakkad
46	CUM 46	Kuttikattoor	Kozhikode
47	CUM 47	Guruvayur	Thrissur
48	CUM 48	Kunnamkulam	Thrissur
49	CUM 49	Thiruvazhiyode	Palakkad
50	CUM 50	Peringode	Palakkad

Table 3.2 Accessions of *Kaempferia galanga* L. studied

Sl No.	Accession No.	Source	District

1	CUK 1	Karimba	Palakkad
2	CUK 2	Karakurussi	Palakkad
3	CUK 3	Kanjirappuzha	Palakkad
4	CUK 4	Alathur	Palakkad
5	CUK 5	Thachampara	Palakkad
6	CUK 6	Kalpathy	Palakkad
7	CUK 7	Kongad	Palakkad
8	CUK 8	Parali	Palakkad
9	CUK 9	Kollengode	Palakkad
10	CUK 10	Chittur	Palakkad
11	CUK 11	Malampuzha	Palakkad
12	CUK 12	Pathirippala	Palakkad
13	CUK 13	Thattamangalam	Palakkad
14	CUK 14	Wadakanchery	Thrissur
15	CUK 15	Kottapuram	Palakkad
16	CUK 16	Kadampazhipuram	Palakkad
17	CUK 17	Kalladikode	Palakkad
18	CUK 18	Perinthalmanna	Malappuram
19	CUK 19	Aryampavu	Palakkad
20	CUK 20	Mannarkkad	Palakkad
21	CUK 21	Puduppariyaram	Palakkad
22	CUK 22	Pudunagaram	Palakkad
23	CUK 23	Cherpalacheri	Palakkad
24	CUK 24	Pulappatta	Palakkad
25	CUK 25	Kanjikkode	Palakkad
26	CUK 26	Ottappalam	Palakkad
27	CUK 27	Mukkam	Kozhikode
28	CUK 28	Kottepram	Kozhikode
29	CUK 29	Thrissur	Thrissur
30	CUK 30	Irinjalakkuda	Thrissur
31	CUK 31	Mundur	Palakkad
32	CUK 32	Calicut University	Malappuram
33	CUK 33	Elappulli	Palakkad
34	CUK 34	Yakkara	Palakkad
35	CUK 35	Puthur	Palakkad
36	CUK 36	Vallikkode	Palakkad
37	CUK 37	Ponnenkode	Palakkad
38	CUK 38	Alanallur	Palakkad
39	CUK 39	Melattur	Malappuram
40	CUK 40	Nilambur	Malappuram

41	CUK 41	Mankave	Kozhikode
42	CUK 42	Nenmini	Malappuram
43	CUK 43	Thirvananthapuram	Thiruvananthapuram
44	CUK 44	Velliparamba	Kozhikode
45	CUK 45	Manjeri	Malappuram
46	CUK 46	Mayanad	Kozhikode
47	CUK 47	Peringode	Palakkad
48	CUK 48	Mangalamkunnu	Palakkad
49	CUK 49	Vadakkanthara	Palakkad
50	CUK 50	Mannuthi	Thrissur

Fresh, healthy rhizomes were collected from different localities in March/April 2005 and planted in the first week of May 2005. The rhizomes were separated into fingers and one finger each planted in 38 cm x 35 cm polybags filled with garden soil, sand and enriched compost in 4:1:1 ratio. *Gliricidia sepium* (Jacq.) Kunth ex Walp leaf mulch was provided occasionally. 60 gm of enriched compost was applied to each plant at the end of the second month and fourth month. Weeding was carried out regularly and optimum soil moisture was maintained. The plants were grown organically except for plant protection and package of practices of Kerala Agricultural University (Anonymous, 2003a) was followed for plant protection.

Data on growth, yield and rhizome characters were recorded in the case of both the species at the end of six months by destructive sampling (Tables 3.3 and 3.4). The data were analyzed as described below so as to study the genetic variability, correlation of characters, character association, genetic divergence, overall performance of the genotypes, performance of plants based on the status of planting material used and rhizome branching pattern.

Fig. 3.1. *Curcuma amada* Roxb. in the experimental layout

Fig. 3.2. *Curcuma amada* Roxb. - Single plant, inflorescence and rhizome

Fig. 3.3. *Kaempferia galanga* L. in the experimental layout

Fig. 3.4. *Kaempferia galanga* L. - Single plant, inflorescence and rhizome

Table 3.3. Characters of *Curcuma amada* Roxb. observed for the study of genetic variability

Sl. No.	Character
1.	Plant height (cm)
2.	Number of tillers
3.	Number of leaves per tiller
4.	Leaf length (cm)
5.	Leaf breadth (cm)
6.	Leaf area (cm^2)
7.	Number of primary fingers
8.	Number of secondary fingers
9.	Length of primary fingers (cm)
10.	Length of secondary fingers (cm)
11.	Diameter of primary fingers (cm)
12.	Diameter of secondary fingers (cm)
13.	Length of mother rhizome (cm)
14.	Diameter of mother rhizome (cm)
15.	Yield per plant (g)

Table 3.4. Characters of *Kaempferia galanga* L. observed for the study of genetic variability

Sl. No.	Character
1.	Plant height (cm)
2.	Number of leaves
3.	Leaf length (cm)
4.	Leaf breadth (cm)
5.	Leaf area (cm^2)
6.	Number of primary fingers
7.	Number of secondary fingers
8.	Length of primary fingers (cm)
9.	Length of secondary fingers (cm)
10.	Diameter of primary fingers (cm)
11.	Diameter of secondary fingers (cm)
12.	Length of mother rhizome (cm)

13. Diameter of mother rhizome (cm)
14. Yield per plant (g)

3.3.1. Genetic variability

The efficiency of selection depends on the extent of genetic variability observed in the case of any species. Genetic improvement is normally achieved by selecting the genotypes with desirable qualities from the available population. Moreover, the unthreatened occurrence of the species on the earth surface is ensured only if the species show high genetic variability.

Genetic variability of *Curcuma amada* and *Kaempferia galanga* has been studied presently using the following tools of analysis.

3.3.1.1. Frequency distribution of growth and yield characters

Frequency distribution analysis of the germplasm of *Curcuma amada* and *Kaempferia galanga* collected for the purpose has been carried out presently so as to analyze the nature of frequency distribution of characters in the germplasm and also to study the nature of genetic control of the characters. Data on 450 plants each grown for the purpose were pooled and analyzed for growth and yield characters at the age of 180 days.

3.3.1.2. Phenotypic and genotypic variability

3.3.1.2.1. Variability of agronomic characters

Variability of agronomic characters in the case of both the plant species under study has been assessed presently by the analysis of mean and standard deviation of the characters.

Analysis of variance (ANOVA) was carried out to test the significance of variation between the genotypes studied presently. F value was calculated for the

purpose and its significance was tested with reference to standard F table. (Fischer and Yates, 1963). CD was calculated with the following formula:

$$CD = t_{0.05} \times \sqrt{\frac{2VE}{r}}$$

Where $t_{0.05}$ is $t_{0.05}$ for error degree of freedom; VE is the error mean square and r is the number of replications.

Genotypic and phenotypic variances of the different characters were estimated as per Singh and Choudhary (1985) using the formula

$$\text{Genotypic variance } (\sigma^2 g) = \frac{\text{MSS for treatment} - \text{MSS for error}}{\text{Number of replications}}$$

$$\text{Phenotypic variance } (\sigma^2 p) = \sigma^2 g + \sigma^2 e$$

where $\sigma^2 e$ is the error variance.

Genotypic and phenotypic co-efficients of variation were estimated following Burton and Devane (1953). Since different traits may be measured in different units, the co-efficients of variation are useful for comparing their relative variabilities (Stansfield, 1991).

$$\text{Genotypic coefficient of variation (GCV)} = \frac{\sigma g}{\overline{X}} \times 100$$

$$\text{Phenotypic coefficient of variation (PCV)} = \frac{\sigma p}{\overline{X}} \times 100$$

where

σg = genotypic standard deviation; σp = Phenotypic standard deviation;

$\overline{X}$ = grand mean of the character

3.3.1.2.2. Heritability of agronomic characters

The extent of variation due to genetic differences among the genotypes can be used to estimate the relative contribution of the genotype and environment in the form of heritability. The parameter of heritability (broad sense) involves all types of gene action and thus forms a broad estimate of heritability (Chahal and Gosal, 2002). It is the fraction of the total variance that is heritable and is estimated as the percentage of genotypic variance over phenotypic variance (Jain, 1982).

Heritability (broad sense) $H^2 = \frac{\sigma^2 g}{\sigma^2 p} \times 100$

3.3.1.2.3. Genetic advance under selection

Genetic advance is the genetic improvement of the progeny possible through selection over the original population (Chahal and Gosal, 2002). This is calculated using the formula

$$GA = \frac{KH^2 \sigma p}{\overline{X}}$$

(Singh and Choudhary, 1985).

where

H^2 = Heritability (broad sense); σp = Phenotypic standard deviation;

K = Selection differential which is 2.06 at 5% intensity of selection in large samples (Allard, 1960).

3.3.2. Correlation of characters

Characters of organisms show different degrees of interrelationships. The systematic interrelationship between the variables is termed correlation. Correlation coefficient of characters has been worked out presently as per Rangaswamy (1995).

3.3.3. Character association

Study of association of characters is carried out for grouping of variables and data reduction so as to find out the lead characters that can be considered in selection. Factor analysis by means of principal component analysis has been done for the purpose presently using the statistical software STATISTICA.

3.3.4. Genetic divergence

Study of genetic divergence among the 50 genotypes each of *Curcuma amada* Roxb. and *Kaempferia galanga* L. was carried out by principal component analysis using the statistical software STATISTICA following UPGMA (Unweighted Pair Group Method with Arithmetic mean) of Sneath and Sokal (1973).

3.3.5. Performance analysis of the accessions collected

Comparative performance of the accession of *Curcuma amada* Roxb. and *Kaempferia galanga* L. has been analyzed presently based on major growth and yield characters with the help of performance index calculated as per Amaravenmathy and Srinivasan (2003). To calculate performance index, accession mean of the characters were divided by the grand mean of the corresponding character in the experimental population.

$$\text{Performance index} = \frac{\text{Accession mean of the character}}{\text{Grand mean of the character}}$$

3.3.6. Study of performance based on the status of planting materials used

An experiment was designed to find out whether the status of the seed materials selected has any role in the growth and yield of the crop by using mother rhizome, primary fingers and secondary fingers as the planting materials. Healthy seed rhizomes from selected mother rhizome, primary fingers and secondary fingers in the case of *Curcuma amada* and *Kaempferia galanga* were used for the present study. The rhizomes were planted in the first week of May

2006 to observe the growth and yield characters using the same cultural practices as in the case of the previous experiment. The growth and yield characters (Tables 3.5 and 3.6) were observed after 6 months of growth. Rhizome characters and yield per plant were observed by destructive sampling. The data were pooled and analyzed statistically for comparative performance.

Table 3.5. Characters of *Curcuma amada* Roxb. studied for comparative performance of yield

Sl. No.	Character
1	Days for germination
2.	Plant height (cm)
3.	Number of tillers
4.	Number of leaves per tiller
5.	Leaf length (cm)
6.	Leaf breadth (cm)
7.	Leaf area (cm^2)
8.	Number of primary fingers
9.	Number of secondary fingers
10.	Length of primary fingers (cm)
11.	Length of secondary fingers (cm)
12.	Diameter of primary fingers (cm)
13.	Diameter of secondary fingers (cm)
14.	Length of mother rhizome (cm)
15.	Diameter of mother rhizome (cm)
16.	Yield per plant (g)

Table 3.6. Characters of *Kaempferia galanga* L. studied for comparative performance of yield

Sl. No.	Character
1	Days for germination
2.	Plant height (cm)
3.	Number of leaves
4.	Leaf length (cm)
5.	Leaf breadth (cm)

6. Leaf area (cm^2)
7. Number of primary fingers
8. Number of secondary fingers
9. Length of primary fingers (cm)
10. Length of secondary fingers (cm)
11. Diameter of primary fingers (cm)
12. Diameter of secondary fingers (cm)
13. Length of mother rhizome (cm)
14. Diameter of mother rhizome (cm)
15. Yield per plant (g)

3.3.7. Study of rhizome branching

Zingiberaceous rhizomes show peculiar type of branching in different species. An experiment was conducted presently to study the branching pattern of rhizomes in *Curcuma amada* Roxb. and *Kaempferia galanga* L. The rhizomes of both the species were observed and branching pattern studied. Necessary drawings have been made and presented elsewhere so as to interpret the branching pattern in the two species.

Chapter IV

RESULTS AND DISCUSSION

The monocot family Zingiberaceae is well represented in the tropical part of the world with more than 50 genera and 1200 species (Kress *et al*., 2002). *Curcuma amada* Roxb. and *Kaempferia galanga* L. are two potentially important species of the family, investigated and exploited only to a limited extent. The present study is to analyse the two species based on their genetic variability, character association, genetic divergence, performance and rhizome branching pattern. The study was conducted in the Genetics and Plant Breeding Division of the Department of Botany, University of Calicut, Kerala, India based on accessions collected from farmer sources from different parts of Kerala state of India. The data observed for the purpose are presented and discussed below under appropriate heads.

4.1. *Curcuma amada* Roxb.

4.1.1. Genetic variability

4.1.1.1. Frequency distribution of growth and yield characters

Study of frequency distribution gives a basic idea of the genetic control of characters and the nature of distribution of dominant and recessive alleles in the gene pools of the characters. 450 plants of *Curcuma amada* Roxb. were grown as described elsewhere and data on growth and yield characters observed at the age of 180 days and pooled for frequency distribution analysis (Table 4.1).

Plant height of *Curcuma amada* showed almost typical normal distribution with a bell shaped frequency curve (Table 4.1). Plant height varied from 45 cm to 150 cm and majority of the plants showed plant height between 75 cm and 105 cm.

Number of tillers varied from 1 to 4. However majority of the plants produced 1 to 2 tillers. Plants with 3 to 4 tillers were very low in frequency. The frequency distribution of number of tillers shows high concentration of plants towards low tillering type. However plants with average number of tillers were about $1/4^{th}$ of the distribution.

Number of leaves per tiller varied from 4 to 14 and majority of the plants showed 6 to 10 leaves per tiller. The frequency distribution of number of leaves per tiller showed high concentration of plants towards the median leaf number and sudden decline of frequency towards both the sides of the graph.

Leaf length, leaf breadth and leaf area also showed continuous frequency distribution. However majority of the plants showed leaf characters below the central value. This shows that frequency of recessive alleles for the character was higher in the gene pool of leaf characters.

Number of primary fingers and secondary fingers per plant showed almost the same distribution pattern in the *Curcuma amada* plants studied. Majority of the plants were below the median class in both the cases and this shows higher frequency of recessive alleles in the gene pool of the characters. This indicates the possibility of selection of desirable plants from the germplasm collected presently in the case of number of primary and secondary fingers.

Length of primary and secondary fingers also showed continuous distribution and higher frequency of plants were around the median value. However plants with higher length of primary and secondary fingers were low in number and this condition indicates the need of selection of favourable genotypes in the case of these characters.

Diameter of primary and secondary fingers also showed continuous distribution. The plants were almost equally distributed towards both the halves of the graph in the case of diameter of primary fingers. In the case of diameter of secondary fingers majority of the plants belongs to the post median classes showing that the frequency of plants with large secondary fingers was higher.

Length of mother rhizome showed almost normal distribution with higher frequency of plants towards first half of the distribution. In the case of diameter of mother rhizome, majority of the plants were below the central value thus showing the need of selection in the case of this character.

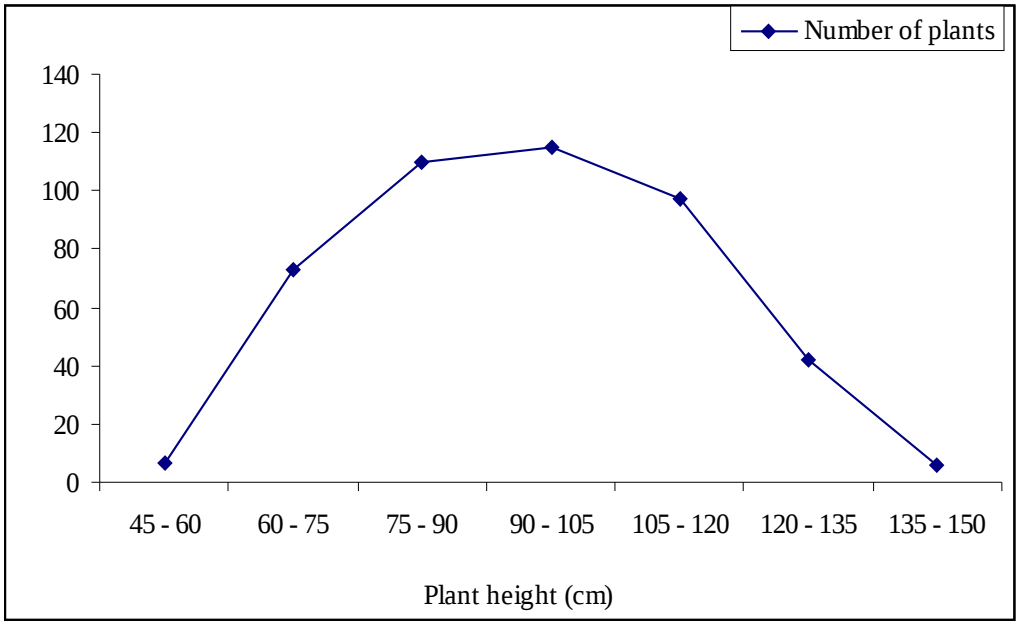
Yield per plant was below the median value in majority of the cases. Only a few plants segregated towards the second half of the graph which shows the existence of very high variability in the case of this character and need of selection of desirable genotypes.

The above study shows that the agronomic characters of *Curcuma amada* Roxb. show continuous frequency distribution which indicates polygenic control. Plant height shows a balanced distribution of dominant and recessive alleles. In the case of length of primary fingers and diameter of secondary fingers, the frequency of dominant alleles has been found to be higher as evidenced by the higher number of plants towards the second half of the frequency distribution. In the case of all the other characters, the frequency of plants towards the first half of the distribution is higher and this indicates the presence of higher number of recessive alleles in their gene pools and it implies the necessity of selection of plants with desirable characters for crop improvement purposes. Even though plants with high yield were available in the germplasm, their frequency was very low. This shows that selection for yield and yield component characters is very important in the genetic stock of *Curcuma amada* occurring in Kerala. Frequency

distribution analysis has been carried out by different workers like Dharmaraj and Sreenivasan (1992), Raghu *et al*. (2003) and Nikhila (2007) in coffee; Paramasivan and Sreerangasamy (1988) in rice; Jayasree (2002) in butterfly pea; Chandramohanan and Mohanan (2005) in *Cassia tora* and Umamaheswari and Mohanan (2004) in vanilla. Such works have been useful in studying the genetic control of agronomic characters and the distribution of alleles in the respective gene pools.

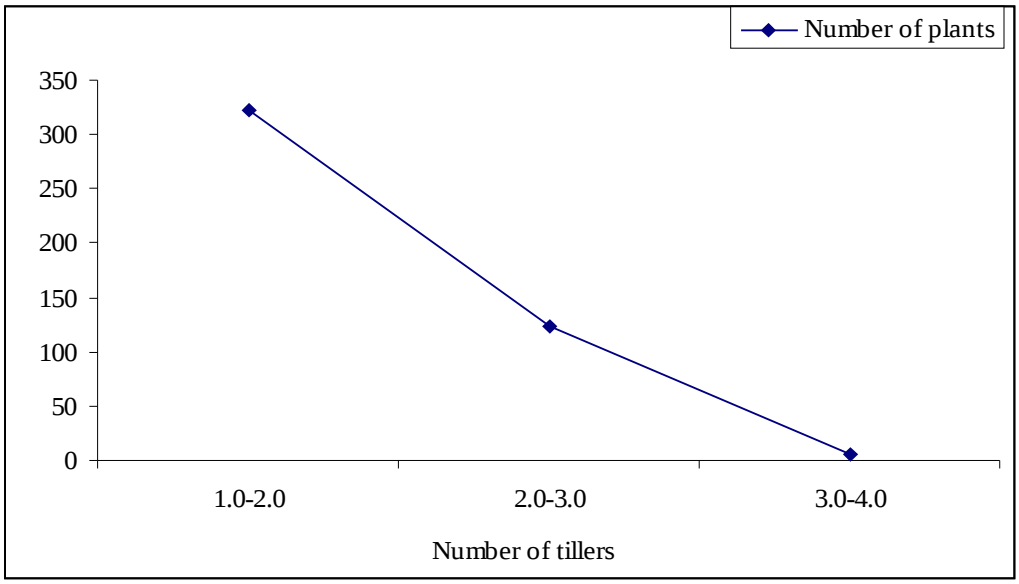
Table 4.1. Frequency distribution of the growth and yield characters in *Curcuma amada* Roxb.

Character / Distribution	Number of plants
1. Plant height (cm)	
45 - 60	7
60 - 75	73
75 - 90	110
90 - 105	115
105 - 120	97
120 - 135	42
135 - 150	6



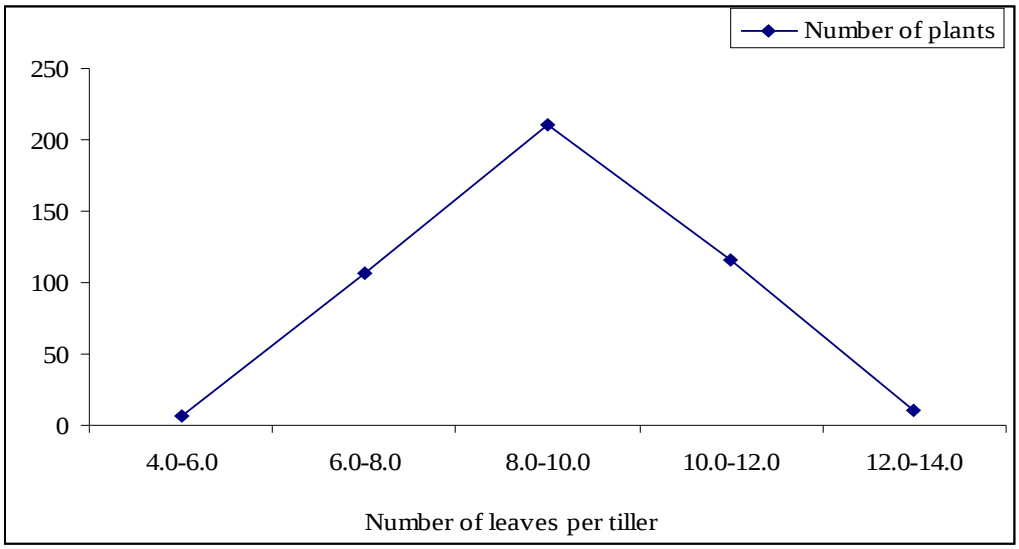
2. Number of tillers

1 - 2	322
2 - 3	123
3 - 4	5



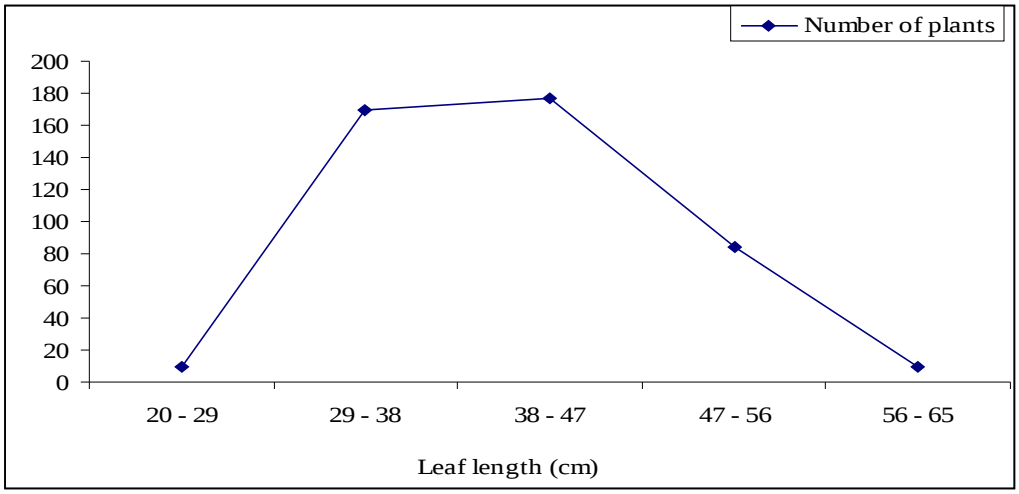
3. Number of leaves per tiller

4 - 6	7
6 - 8	106
8 - 10	211
10 - 12	116
12 - 14	10



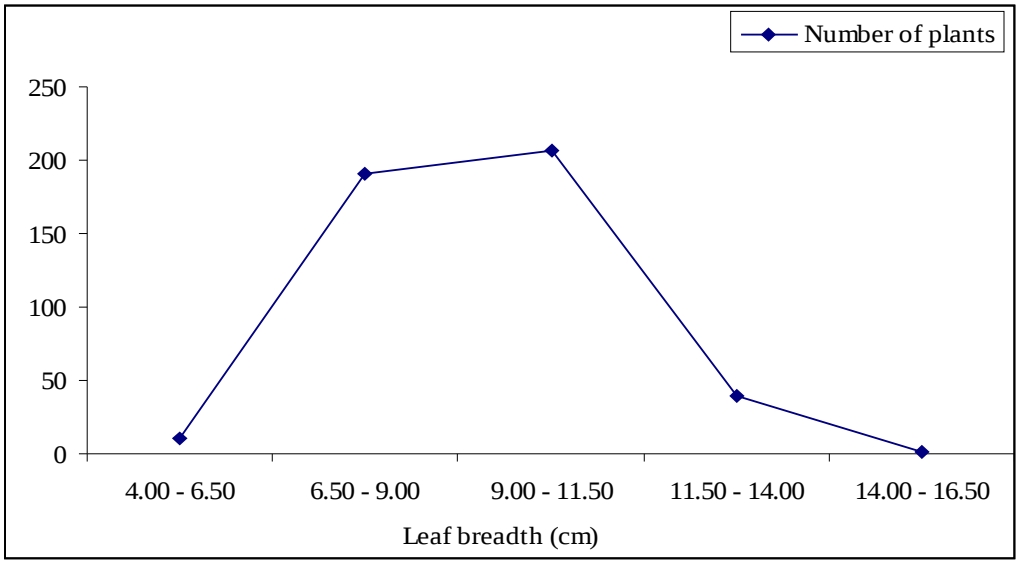
4. Leaf length (cm)

20 - 29	10
29 - 38	169
38 - 47	177
47 - 56	84
56 - 65	10



5. Leaf breadth (cm)

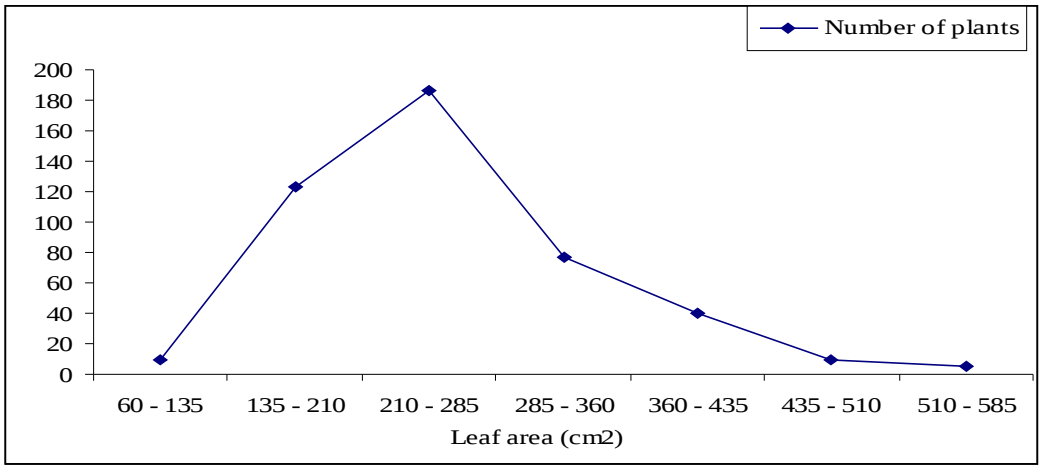
4.00 - 6.50	11
6.50 - 9.00	191
9.00 - 11.50	207
11.50 - 14.00	40
14.00 - 16.50	1



6. Leaf area (cm^2)

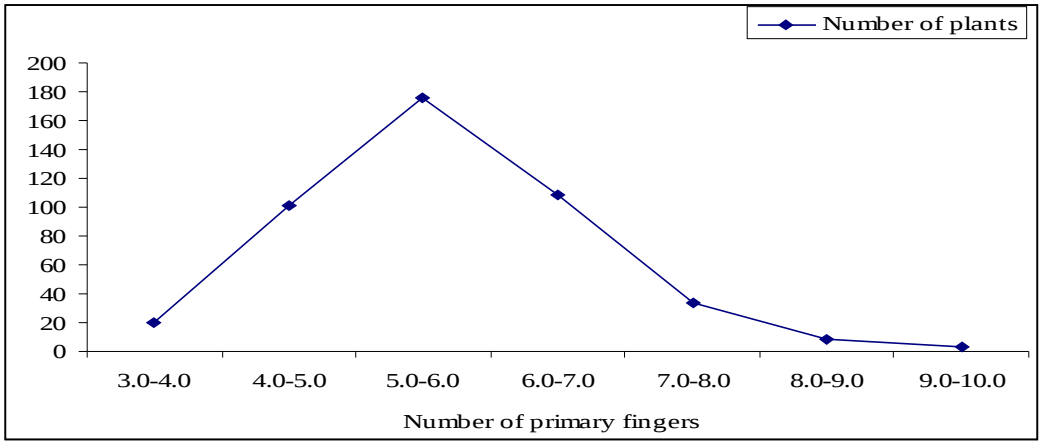
60 - 135

135 - 210	123
210 - 285	186
285 - 360	77
360 - 435	40
435 - 510	10
510 - 585	5



7. Number of primary fingers

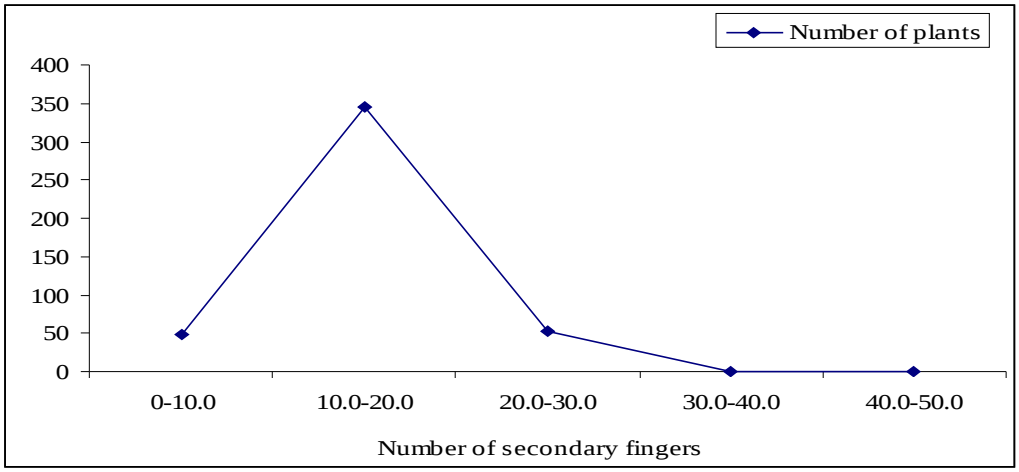
3 - 4	20
4 - 5	101
5 - 6	176
6 - 7	108
7 - 8	34
8 - 9	8
9 - 10	3



8. Number of secondary fingers

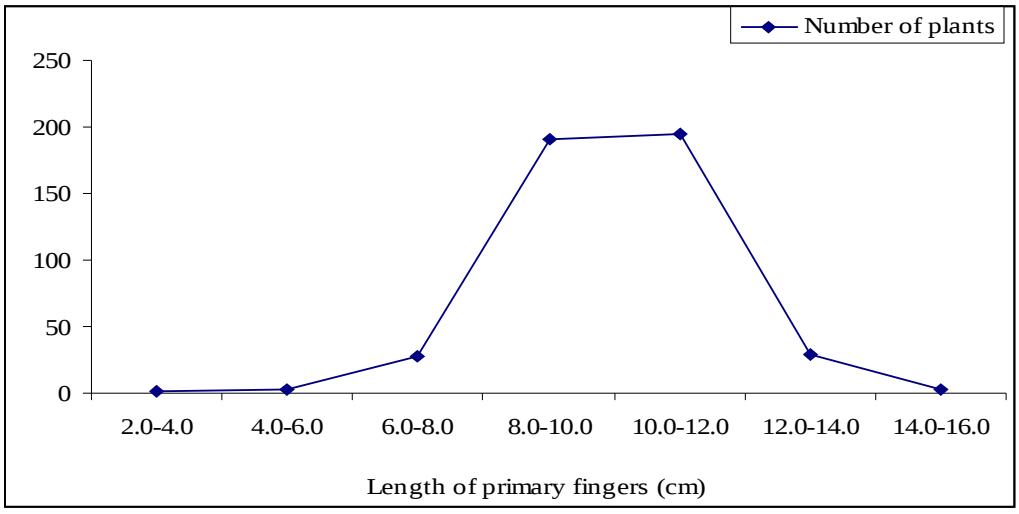
0 - 10	49

10 - 20	346
20 - 30	53
30 - 40	1
40 - 50	1



9. Length of primary fingers (cm)

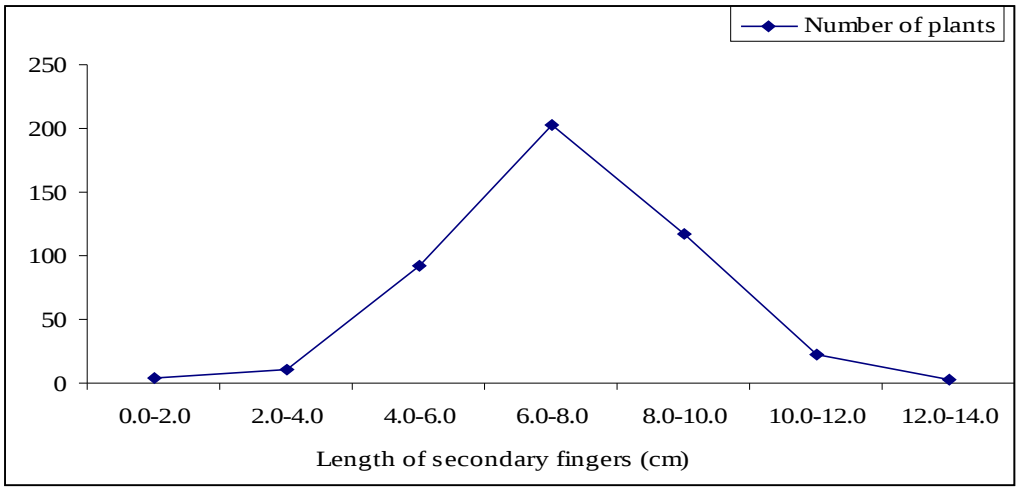
2 - 4	1
4 - 6	3
6 - 8	28
8 - 10	191
10 - 12	195
12 - 14	29
14 - 16	3



10. Length of secondary fingers (cm)

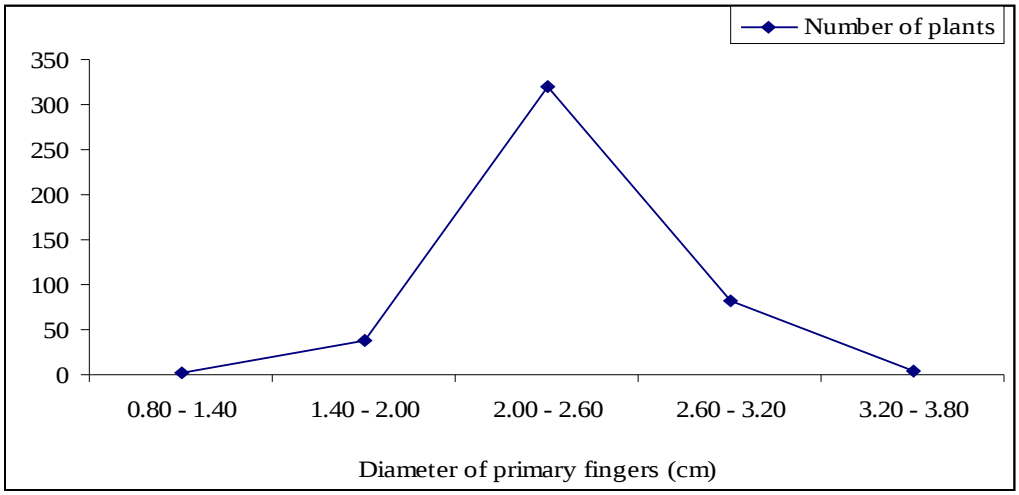
0 - 2	4

2 - 4	10
4 - 6	92
6 - 8	202
8 - 10	117
10 - 12	23
12 - 14	2



11. Diameter of primary fingers (cm)

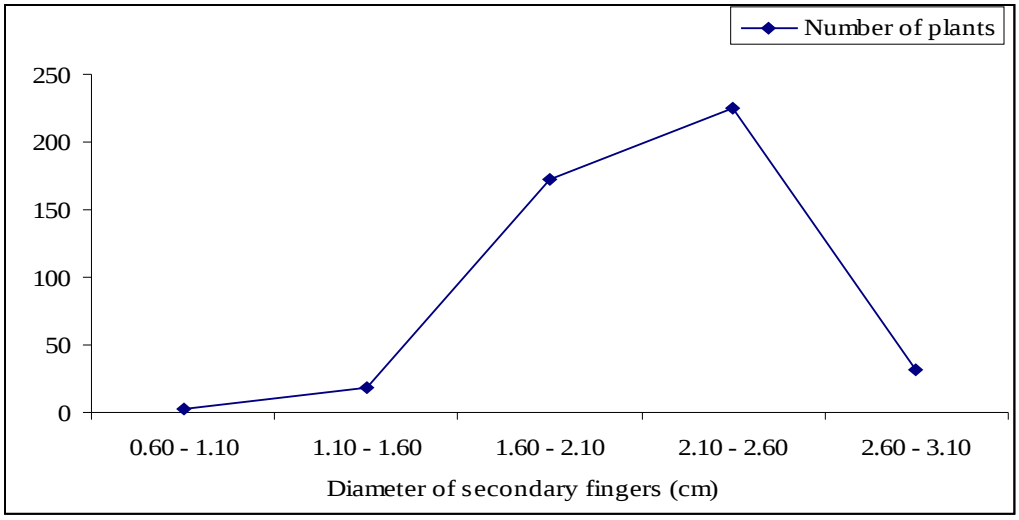
0.80 - 1.40	2
1.40 - 2.00	39
2.00 - 2.60	321
2.60 - 3.20	83
3.20 - 3.80	5



12. Diameter of secondary fingers (cm)

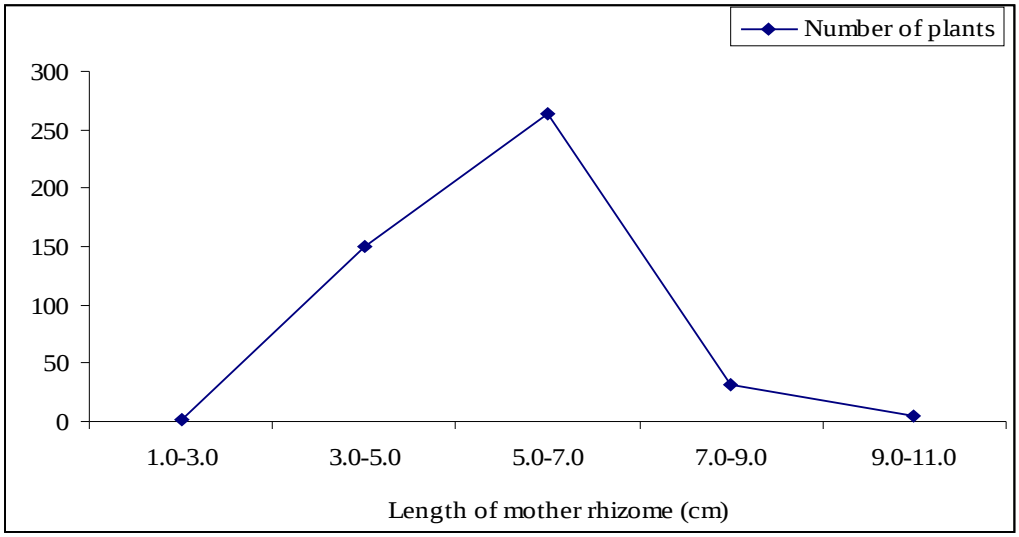
0.60 - 1.10	3

1.10 - 1.60	18
1.60 - 2.10	172
2.10 - 2.60	225
2.60 - 3.10	32



13. Length of mother rhizome (cm)

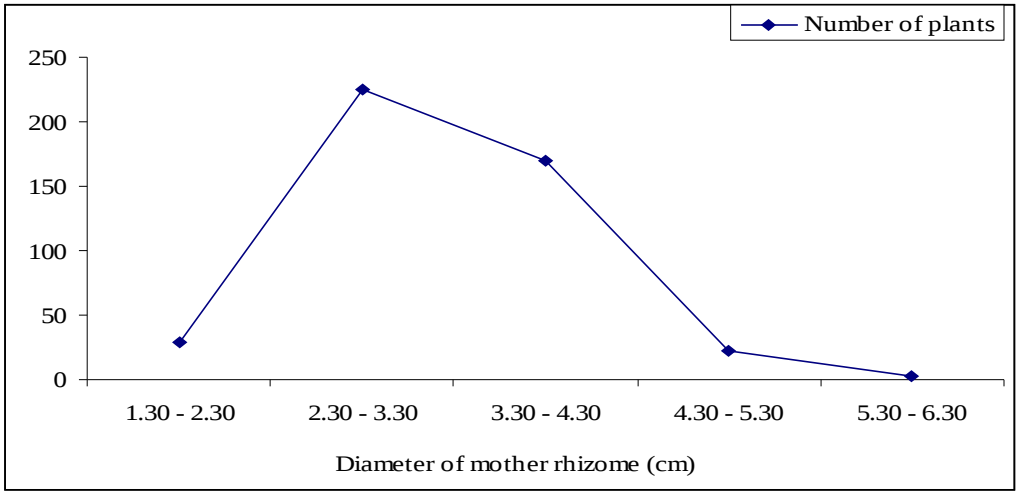
1 - 3	1
3 - 5	150
5 - 7	264
7 - 9	31
9 - 11	4



14. Diameter of mother rhizome (cm)

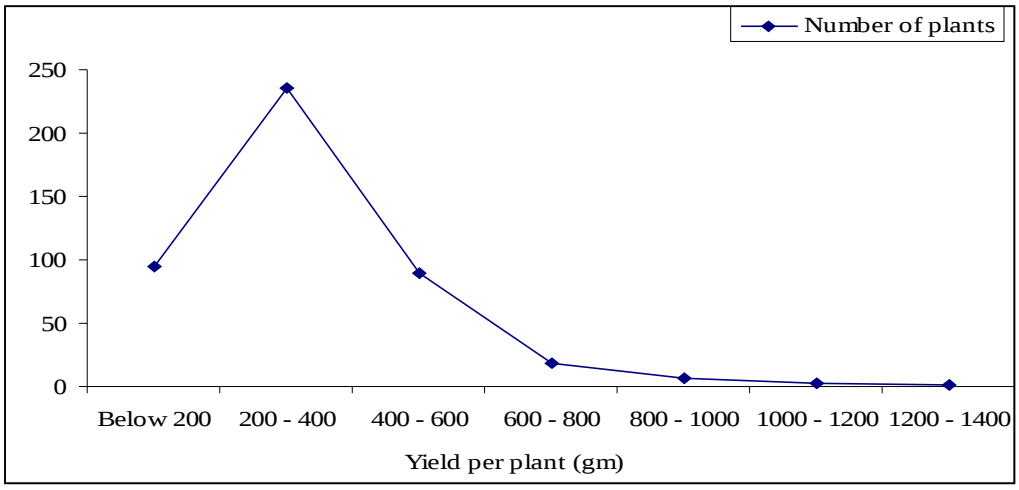
1.30 - 2.30	29

2.30 - 3.30	225
3.30 - 4.30	170
4.30 - 5.30	23
5.30 - 6.30	3



15. Yield per plant (g)

0 - 200	95
200 - 400	236
400 - 600	90
600 - 800	19
800 - 1000	6
1000 - 1200	3
1200 - 1400	1



4.1.1.2. Phenotypic and genotypic variability

Curcuma amada Roxb. is an underexploited species of Zingiberaceae with food and medicinal potential. Only a very few crop improvement studies had been carried out in this crop. New trends in agriculture and new life styles of peasant communities have resulted in the neglect of several alternate and supplementary food and medicinal sources and *Curcuma amada* is not an exception. However, the crop is represented in the homesteads of Kerala even now with considerably high variation. The present study was an effort to collect the materials from the homestead gardens of Kerala, to catalogue them and to study them for their variability and improvement potential.

4.1.1.2.1. Variability of agronomic characters

Phenotypic and genotypic variability of agronomic characters in *Curcuma amada* Roxb. has been studied presently based on six growth characters and nine yield characters (Tables 4.2 and 4.3). All the characters showed statistically significant variations between accessions. Mean plant height was 94.32 cm, number of tillers 1.29, number of leaves per tiller 8.53, leaf length 40.55 cm, leaf breadth 9.22 cm, leaf area 258.97 cm^2, number of primary fingers 5.18, number of secondary fingers 14.75, length of primary fingers 9.99 cm, length of secondary fingers 7.15 cm, diameter of primary fingers 2.36 cm, diameter of secondary fingers 2.15 cm, length of mother rhizome 5.30 cm, diameter of mother rhizome 3.24 cm and yield per plant 329.07 gm.

Among the growth characters the highest coefficient of variation was shown by number of tillers (22.48%) followed by leaf area (21.72%) and lowest coefficient of variation by number of leaves per tiller (9.14%). Plant height showed a coefficient of variation of 16.86%, leaf length showed a coefficient of variation of 13.49% and leaf breadth showed 9.87% as coefficient of variation. Among the yield characters the highest coefficient of variation was shown by yield per plant (28.15%). The coefficient of variation in the case of number of

primary fingers was 8.88%, in the case of number of secondary fingers 14.24%, in the case of length of primary fingers 7.41%, in the case of length of secondary fingers 14.27%, in the case of diameter of primary fingers 6.78%, in the case of diameter of secondary fingers 8.37%, in the case of length of mother rhizome 9.25% and in the case of diameter of mother rhizome 11.73%.

The above observation shows that among the growth characters leaf area and number of tillers are the most variable and in the case of yield characters yield per plant is the most variable.

Table 4.2. Genetic variability of the morphological characters of *Curcuma amada* Roxb. studied (vegetative characters)

Acc. No.	Plant height (cm) **	Number of tillers **	Number of leaves per tiller **	Leaf length (cm) **	Leaf breadth (cm) **	Leaf area (cm^2) **
CUM 1	98.72 ± 5.98	1.00 ± 0.00	8.67 ± 0.88	40.30 ± 2.88	8.76 ± 0.70	243.24 ± 38.82
CUM 2	117.95 ± 5.91	1.10 ± 0.17	9.33 ± 0.33	50.06 ± 2.70	10.08 ± 0.11	350.00 ± 9.63
CUM 3	115.50 ± 12.27	1.33 ± 0.35	8.22 ± 0.51	48.17 ± 7.09	10.17 ± 1.58	341.69 ± 100.05
CUM 4	112.33 ± 9.50	1.20 ± 0.17	9.78 ± 0.39	49.32 ± 5.53	10.02 ± 1.88	340.52 ± 93.21
CUM 5	102.33 ± 7.06	1.00 ± 0.00	8.33 ± 1.20	41.61 ± 3.00	9.33 ± 1.12	268.65 ± 52.07
CUM 6	104.89 ± 7.91	1.00 ± 0.00	8.67 ± 0.33	43.83 ± 1.36	8.84 ± 0.48	268.55 ± 22.31
CUM 7	94.95 ± 10.60	1.00 ± 0.00	8.56 ± 1.02	40.63 ± 4.62	7.85 ± 0.49	217.49 ± 28.23
CUM 8	93.89 ± 15.72	1.10 ± 0.17	9.00 ± 0.67	39.78 ± 6.26	7.81 ± 1.07	215.58 ± 64.30
CUM 9	107.11 ± 3.84	1.23 ± 0.40	8.78 ± 0.77	40.81 ± 1.69	8.38 ± 0.38	233.59 ± 3.01
CUM 10	104.28 ± 9.53	1.23 ± 0.40	9.40 ± 0.51	41.48 ± 2.48	8.49 ± 1.32	244.85 ± 44.30
CUM 11	100.17 ± 9.92	1.00 ± 0.00	9.55 ± 0.69	41.55 ± 3.15	8.62 ± 0.53	245.39 ± 31.94

CUM 12	103.11 ± 8.76	1.00 ± 0.00	9.22 ± 0.51	43.68 ± 3.29	8.34 ± 0.63	248.66 ± 37.88
CUM 13	109.44 ± 8.62	1.33 ± 0.35	8.78 ± 0.51	43.37 ± 3.90	8.62 ± 0.95	256.82 ± 40.87
CUM 14	107.56 ± 16.76	1.10 ± 0.17	9.11 ± 0.70	41.61 ± 3.14	8.46 ± 1.13	248.72 ± 53.23
CUM 15	112.50 ± 14.21	1.10 ± 0.17	8.22 ± 1.07	45.46 ± 6.79	8.98 ± 1.06	283.36 ± 74.71
CUM 16	107.11 ± 13.52	1.10 ± 0.17	8.89 ± 0.51	42.77 ± 3.31	9.04 ± 0.94	265.76 ± 46.37
CUM 17	115.61 ± 1.99	1.00 ± 0.00	9.22 ± 0.39	46.89 ± 2.94	9.53 ± 0.77	309.12 ± 42.88
CUM 18	114.44 ± 5.98	1.00 ± 0.00	9.22 ± 0.19	47.62 ± 5.14	9.64 ± 0.30	310.61 ± 32.03
CUM 19	107.11 ± 1.26	1.10 ± 0.17	8.89 ± 0.70	45.49 ± 2.38	9.92 ± 0.98	311.52 ± 46.00
CUM 20	88.72 ± 5.43	1.00 ± 0.00	8.34 ± 0.58	39.00 ± 4.02	8.41 ± 0.78	225.02 ± 44.67
CUM 21	101.61 ± 4.92	1.00 ± 0.00	9.67 ± 0.00	43.94 ± 1.93	8.86 ± 0.42	255.14 ± 18.80
CUM 22	91.39 ± 3.88	1.00 ± 0.00	8.44 ± 0.20	38.70 ± 2.37	8.30 ± 0.35	219.72 ± 19.64
CUM 23	87.52 ± 5.66	1.33 ± 0.35	8.11 ± 1.26	37.89 ± 2.95	9.25 ± 0.45	239.10 ± 27.81
CUM 24	80.67 ± 2.05	1.70 ± 0.00	7.57 ± 0.51	35.57 ± 2.05	8.63 ± 0.52	211.01 ± 21.66
CUM 25	86.72 ± 2.13	1.10 ± 0.17	8.89 ± 0.38	37.72 ± 0.92	9.02 ± 0.33	231.88 ± 12.81
CUM 26	82.78 ± 8.67	1.10 ± 0.17	7.78 ± 0.19	34.77 ± 2.70	8.62 ± 0.98	205.54 ± 38.62
CUM 27	90.28 ± 2.85	1.43 ± 0.23	8.33 ± 0.88	38.61 ± 0.44	9.68 ± 0.45	254.46 ± 11.85
CUM 28	89.55 ± 5.01	1.43 ± 0.23	8.11 ± 1.26	39.03 ± 2.84	9.64 ± 0.25	257.80 ± 22.66
CUM 29	63.72 ± 13.28	1.33 ± 0.58	8.44 ± 2.14	30.34 ± 6.13	7.36 ± 1.47	156.58 ± 56.95
CUM 30	75.12 ± 7.72	1.80 ± 0.17	7.78 ± 0.77	37.13 ± 4.01	9.49 ± 1.30	242.48 ± 54.90
CUM 31	107.83 ± 0.93	1.43 ± 0.23	8.45 ± 1.07	46.96 ± 0.41	10.29 ± 1.35	319.76 ± 59.17
CUM 32	114.07 ± 3.44	1.00 ± 0.00	10.22± 0.77	48.64 ± 1.55	10.88 ± 0.60	361.81 ± 26.25
CUM 33	111.28 ±	1.20 ±	8.78 ±	48.40 ±	11.61 ±	397.45 ±

	6.08	0.17	1.02	2.01	0.79	48.05
CUM 34	110.50 ± 4.52	1.43 ± 0.51	9.22 ± 1.50	48.33 ± 2.20	11.41 ± 0.44	375.30 ± 23.81
CUM 35	114.00 ± 3.92	1.43 ± 0.51	8.67 ± 1.20	48.69 ± 1.38	10.88 ± 0.50	362.62 ± 15.61
CUM 36	109.11 ± 3.85	1.43 ± 0.23	8.78 ± 1.57	46.59 ± 0.97	11.01 ± 0.56	350.86 ± 23.97
CUM 37	96.72 ± 3.62	1.10 ± 0.17	9.22 ± 1.07	41.84 ± 2.59	10.06 ± 1.07	290.60 ± 47.29
CUM 38	89.45 ± 2.43	1.90 ± 0.17	7.44 ± 1.39	41.37 ± 0.23	9.96 ± 0.35	280.99 ± 10.49
CUM 39	73.67 ± 0.93	1.43 ± 0.23	8.00 ± 0.88	35.35 ± 0.58	9.07 ± 0.41	218.61 ± 8.85
CUM 40	77.89 ± 3.46	1.70 ± 0.00	6.89 ± 0.84	35.33 ± 0.75	8.94 ± 0.17	226.30 ± 12.06
CUM 41	80.28 ± 3.62	1.80 ± 0.17	7.33 ± 0.33	36.11 ± 1.27	9.19 ± 0.32	225.84 ± 2.25
CUM 42	71.55 ± 1.35	1.67 ± 0.35	7.33 ± 1.00	33.05 ± 0.66	8.66 ± 0.46	194.89 ± 13.96
CUM 43	78.61 ± 8.88	1.20 ± 0.17	9.78 ± 0.69	34.90 ± 2.92	9.20 ± 0.64	220.28 ± 33.99
CUM 44	74.83 ± 4.05	1.33 ± 0.35	8.22 ± 1.17	34.81 ± 1.40	8.46 ± 0.36	200.29 ± 9.92
CUM 45	80.56 ± 1.84	1.00 ± 0.00	8.67 ± 0.33	35.50 ± 2.75	8.73 ± 0.38	210.93 ± 21.58
CUM 46	77.61 ± 8.26	1.30 ± 0.00	7.44 ± 0.84	33.35 ± 2.02	9.03 ± 0.77	206.93 ± 30.39
CUM 47	78.56 ± 5.00	11.67 ± 0.35	7.44 ± 0.36	34.39 ± 2.36	9.26 ± 0.17	217.62 ± 11.99
CUM 48	72.50 ± 5.29	1.90 ± 0.17	7.22 ± 0.19	32.76 ± 0.08	8.87 ± 0.18	198.43 ± 3.75
CUM 49	64.11 ± 0.25	1.90 ± 0.17	7.11 ± 0.70	31.84 ± 1.89	8.55 ± 0.56	187.19 ± 21.76
CUM 50	65.83 ± 2.68	1.67 ± 0.35	9.00 ± 0.33	32.30 ± 1.66	8.93 ± 0.51	199.12 ± 13.90
Mean	94.32	1.29	8.53	40.55	9.22	258.97
Range	46 - 141	1 - 3	5 - 12	21.00 – 61.33	4.43 – 14.80	66.32 – 578.33
SD	15.90	0.29	0.78	5.47	0.91	56.25

CV	16.86	22.48	9.14	13.49	9.87	21.72
CD @ 5%	11.94	0.39	1.41	5.10	1.30	63.98

**: significant at 1% level

In the case of all the characters studied, phenotypic coefficient of variation (PCV) was higher than genotypic coefficient of variation (GCV). This indicates additive polygenic nature of the characters. Among the growth characters the highest PCV was shown by number of tillers (27.13%) followed by leaf area (24.99%) and the lowest by leaf breadth (12.15%). Highest GCV was shown by leaf area (19.89%) followed by number of tillers (18.60%) and the lowest GCV was shown by number of leaves per tiller (6.10%). Among the yield characters the highest PCV was shown by yield per plant (34.76%) and the lowest PCV by diameter of primary fingers (9.32%). The highest GCV was also shown by yield per plant (24.17%) and the smallest GCV by diameter of primary fingers (5.94%) (Table 4.4). Higher GCV indicates higher scope of inheritance of the character to the progeny and high difference between PCV and GCV indicates the influence of environment on the character.

Analysis of phenotypic and genotypic coefficients of variation has been carried out by earlier workers in different crop plants like soybean (Nirmalakumari and Balasubramanian, 1993), arum (Pandey *et al*.,1993), chilli (Pandey and Dobhal, 1993), betel vine (Reddy, 1994), coriander (Tripathi *et al*., 2000), tea (Ramasubramanian, 2005), coffee (Nikhila, 2007), vanilla (Umamaheswari, 2008), *aswagandha* (Kandalkar *et al*., 1993), ginger (Yadav, 1999), cardamom (Backiyarani *et al*., 2002; Radhakrishnan *et al*., 2004; 2006a) and turmeric (Narayanpur and Hanamashetti, 2003; Choudhuri and Hore, 2004; Sinkar *et al*., 2005). Their observations had been useful in assessing the extent of genetic variability in the crops mentioned above. It is hoped that the outcome of the present investigation has provided such information in mango ginger.

4.1.1.2.2. Heritability of agronomic characters

Heritability (broad sense) is the ability of a character to get inherited to its progeny. Usually heritability will be high in the case of oligogenic characters and low in the case of polygenic characters. However most of the agronomic characters of crop plants are polygenic in nature and they are influenced by the environment to some extent and the number of alleles involved and the extent of influence of environment decides the level of heritability. Among the six growth characters and nine yield characters studied in *Curcuma amada*, plant height showed the highest heritability (81.47%) followed by leaf length (73.19%) and leaf area (63.34%). Among the yield characters diameter of mother rhizome showed the highest heritability (57.14%) followed by yield per plant (48.32%). It shows that characters like plant height, leaf length, leaf area, diameter of mother rhizome and yield per plant show high heritability in *Curcuma amada*. Characters like number of tillers, leaf breadth, length of primary fingers, length of secondary fingers, diameter of primary fingers, diameter of secondary fingers and length of mother rhizome also showed comparatively high heritability (Table 4.4).

Differential heritability of agronomic characters and influence of environment on such characters have been studied in different crops by earlier workers like Ganesamurthy *et al.* (2002) in coconut; Narayanpur and Hanamashetti (2003) in turmeric; Radhakrishnan *et al*. (2006a) in cardamom; Bharadwaj *et al*. (2007) in rice and Warkad *et al*. (2008) in sorghum. The workers could generate valuable information based on their studies. However, such information in the case of mango ginger seems to be new.

Table 4.3. Genetic variability of the morphological characters of *Curcuma amada* Roxb. studied (yield characters)

Acc. No.	Number of primary fingers **	Number of secondary fingers **	Length of primary fingers (cm) **	Length of secondary fingers (cm) **	Diameter of primary fingers (cm) **	Diameter of secondary fingers (cm) **	Length of mother rhizome (cm) **	Diameter of mother rhizome (cm) **	Yield Per plant (gm) **
CUM 1	4.44 ± 0.20	14.44 ± 2.22	9.57 ± 0.38	7.02 ± 0.65	2.27 ± 0.02	2.03 ± 0.16	4.97 ± 0.40	2.70 ± 0.06	293.89 ± 45.50
CUM 2	4.55 ± 0.69	18.44 ± 6.11	10.80 ± 0.33	6.68 ± 0.42	2.55 ± 0.19	2.24 ± 0.17	6.61 ± 1.06	2.89 ± 0.10	430.00 ± 82.98
CUM 3	5.11 ± 0.51	17.78 ± 3.10	1.89 ± 1.62	6.60 ± 0.75	2.47 ± 0.20	2.24 ± 0.08	5.40 ± 0.52	2.86 ± 0.26	452.22 ± 215.64
CUM 4	5.11 ± 0.51	17.11 ± 4.67	10.24 ± 0.51	7.04 ± 0.48	2.19 ± 0.18	1.96 ± 0.18	5.61 ± 0.59	2.77 ± 0.37	415.55 ± 104.08
CUM 5	5.44 ± 0.51	13.78 ± 2.34	9.98 ± 0.55	7.08 ± 0.62	2.31 ± 0.31	2.14 ± 0.18	5.91 ± 0.59	3.27 ± 0.35	314.44 ± 68.34
CUM 6	4.45 ± 0.39	15.00 ± 1.73	10.69 ± 0.60	6.65 ± 0.78	2.31 ± 0.20	2.13 ± 0.12	5.77 ± 0.67	3.29 ± 0.43	301.11 ± 37.50
CUM 7	4.33 ± 0.33	12.67 ± 2.19	9.06 ± 0.75	6.37 ± 1.80	2.22 ± 0.24	1.97 ± 0.33	5.10 ± 0.74	2.89 ± 0.28	257.22 ± 140.52
CUM 8	4.78 ± 0.77	14.00 ± 2.02	9.26 ± 0.50	5.47 ± 1.21	2.27 ± 0.29	1.93 ± 0.28	4.67 ± 0.55	2.74 ± 0.43	242.78 ± 62.05
CUM 9	4.78 ± 0.51	14.89 ± 1.35	10.35 ± 0.47	6.44 ± 0.17	2.27 ± 0.18	1.97 ± 0.03	5.07 ± 0.53	2.78 ± 0.11	266.67 ± 36.66
CUM 10	4.89 ± 0.51	13.89 ± 1.35	9.23 ± 1.10	7.05 ± 1.17	2.39 ± 0.07	2.07 ± 0.35	5.42 ± 1.17	3.18 ± 0.29	353.33 ± 98.50

CUM 11	4.55 ± 0.39	12.33 ± 4.05	10.39 ± 0.31	7.17 ± 0.89	2.43 ± 0.11	2.12 ± 0.14	4.82 ± 0.59	2.85 ± 0.19	265.55 ± 48.11
CUM 12	4.89 ± 0.19	15.00 ± 0.33	10.26 ± 0.27	7.18 ± 0.70	2.37 ± 0.02	2.16 ± 0.10	4.70 ± 0.12	2.83 ± 0.22	296.67 ± 21.28
CUM 13	5.22 ± 0.39	14.78 ± 2.01	10.19 ± 0.71	6.54 ± 1.26	2.53 ± 0.21	2.35 ± 0.18	4.98 ± 0.37	2.79 ± 0.20	323.11 ± 16.04
CUM 14	4.89 ± 0.51	14.11 ± 2.55	9.37 ± 1.19	6.63 ± 0.68	2.30 ± 0.13	2.18 ± 0.12	5.11 ± 0.69	2.93 ± 0.16	313.33 ± 65.08
CUM 15	4.89 ± 1.17	12.33 ± 2.03	9.82 ± 0.65	7.18 ± 1.85	2.59 ± 0.18	2.20 ± 0.29	5.27 ± 0.84	3.34 ± 0.62	387.78 ± 183.37
CUM 16	5.00 ± 0.67	14.33 ± 0.66	10.08 ± 0.84	7.59 ± 0.82	2.23 ± 0.16	2.27 ± 0.20	5.34 ± 0.21	3.25 ± 0.05	312.78 ± 61.24
CUM 17	5.22 ± 0.84	16.89 ± 4.25	10.48 ± 1.12	7.71 ± 0.95	2.52 ± 0.16	2.22 ± 0.13	5.70 ± 0.18	3.53 ± 0.16	420.00 ± 184.40
CUM 18	4.56 ± 0.20	13.00 ± 2.08	10.23 ± 0.37	8.28 ± 0.95	2.51 ± 0.24	2.38 ± 0.22	5.72 ± 0.63	3.71 ± 0.09	386.67 ± 59.89
CUM 19	5.00 ± 0.33	16.66 ± 1.15	10.53 ± 0.67	8.11 ± 1.28	2.62 ± 0.18	2.39 ± 0.14	5.17 ± 0.24	3.16 ± 0.02	549.44 ± 174.56
CUM 20	5.00 ± 0.67	14.55 ± 1.84	10.88 ± 0.65	7.34 ± 0.39	2.44 ± 0.05	2.24 ± 0.04	5.49 ± 0.68	3.19 ± 0.24	305.55 ± 99.78
CUM 21	5.11 ± 0.19	16.78 ± 3.91	11.35 ± 0.81	8.45 ± 0.85	2.57 ± 0.11	2.40 ± 0.18	5.35 ± 0.81	3.82 ± 0.35	455.55 ± 87.94
CUM 22	4.11 ± 0.19	12.78 ± 1.50	9.63 ± 0.93	5.49 ± 0.88	2.47 ± 0.07	2.10 ± 0.24	4.62 ± 0.60	2.98 ± 0.36	229.45 ± 32.50
CUM 23	4.55 ± 0.39	13.11 ± 1.65	9.41 ± 0.31	7.41 ± 0.41	2.27 ± 0.08	2.16 ± 0.05	4.94 ± 0.05	3.32 ± 0.12	277.22 ± 54.32
CUM 24	4.67 ± 0.88	17.89 ± 3.27	9.71 ± 0.84	6.36 ± 0.73	2.38 ± 0.25	2.12 ± 0.17	5.30 ± 0.50	3.17 ± 0.25	259.44 ± 43.79

CUM 25	5.56 ± 1.26	15.89 ± 2.83	10.76 ± 1.00	6.56 ± 0.62	2.47 ± 0.10	2.22 ± 0.14	5.04 ± 0.27	3.13 ± 0.37	307.22 ± 54.78
CUM 26	4.22 ± 0.19	11.33 ± 2.10	9.08 ± 0.11	5.18 ± 1.34	2.31 ± 0.26	1.92 ± 0.24	4.90 ± 0.87	3.07 ± 0.50	192.78 ± 92.35
CUM 27	5.44 ± 0.20	16.11 ± 2.22	9.91 ± 0.16	7.35 ± 1.38	2.43 ± 0.14	2.17 ± 0.08	5.40 ± 0.64	3.48 ± 0.20	326.11 ± 51.81
CUM 28	5.33 ± 0.33	15.89 ± 1.50	9.73 ± 1.90	7.54 ± 0.94	2.30 ± 0.18	2.27 ± 0.18	5.03 ± 0.33	3.41 ± 0.47	374.44 ± 92.71
CUM 29	5.33 ± 1.00	9.55 ± 3.89	7.42 ± 1.61	4.61 ± 2.29	1.93 ± 0.37	1.68 ± 0.48	4.27 ± 0.53	2.81 ± 0.20	150.00 ± 49.69
CUM 30	5.00 ± 0.58	15.11 ± 2.79	10.16 ± 0.62	7.05 ± 0.82	2.40 ± 0.12	2.12 ± 0.16	5.37 ± 0.58	3.63 ± 0.36	361.89 ± 105.01
CUM 31	5.67 ± 0.58	16.66 ± 2.08	10.53 ± 0.44	8.73 ± 1.43	2.60 ± 0.14	2.35 ± 0.18	6.05 ± 0.32	3.77 ± 0.10	468.33 ± 111.82
CUM 32	5.33 ± 0.33	15.67 ± 1.00	9.78 ± 0.66	7.54 ± 0.69	2.35 ± 0.06	2.20 ± 0.08	5.65 ± 0.47	3.26 ± 0.23	377.22 ± 58.08
CUM 33	5.89 ± 0.51	16.22 ± 1.07	10.81 ± 0.68	8.64 ± 1.06	2.53 ± 0.10	2.46 ± 0.01	5.57 ± 0.10	3.61 ± 0.12	441.67 ± 98.25
CUM 34	5.56 ± 0.20	18.56 ± 1.26	9.82 ± 0.68	8.87 ± 0.50	2.47 ± 0.12	2.38 ± 0.10	6.17 ± 0.10	3.83 ± 0.16	494.44 ± 33.10
CUM 35	5.56 ± 0.84	17.67 ± 2.08	10.60 ± 0.20	8.03 ± 0.61	2.25 ± 0.12	2.34 ± 0.03	6.16 ± 0.73	3.84 ± 0.73	450.00 ± 55.25
CUM 36	5.33 ± 0.58	13.56 ± 1.02	9.80 ± 0.86	8.26 ± 0.06	2.32 ± 0.22	2.24 ± 0.03	6.16 ± 0.45	4.12 ± 0.19	406.11 ± 19.78
CUM 37	5.00 ± 0.33	13.66 ± 2.08	10.53 ± 0.04	7.76 ± 1.05	2.39 ± 0.08	2.21 ± 0.15	5.45 ± 0.48	3.28 ± 0.48	390.00 ± 61.44
CUM 38	5.33 ± 0.00	17.57 ± 1.50	10.96 ± 0.54	8.85 ± 0.76	2.35 ± 0.03	2.28 ± 0.15	5.44 ± 0.12	3.51 ± 0.30	458.33 ± 15.90

CUM 39	5.78 ± 0.51	15.34 ± 2.52	10.33 ± 0.18	7.02 ± 0.29	2.31 ± 0.04	2.09 ± 0.11	5.87 ± 0.37	3.25 ± 0.10	300.00 ± 17.40
CUM 40	5.44 ± 0.51	16.44 ± 0.77	10.28 ± 0.75	7.42 ± 0.50	2.26 ± 0.08	2.18 ± 0.18	4.89 ± 0.19	3.25 ± 0.11	273.33 ± 52.68
CUM 41	5.55 ± 0.39	15.00 ± 1.86	9.45 ± 0.86	8.45 ± 1.40	2.43 ± 0.27	2.13 ± 0.17	4.49 ± 0.48	3.90 ± 0.44	336.11 ± 46.26
CUM 42	5.33 ± 0.00	15.00 ± 0.88	9.87 ± 0.36	6.69 ± 0.44	2.21 ± 0.03	1.97 ± 0.09	5.09 ± 0.34	3.24 ± 0.14	235.00 ± 43.72
CUM 43	5.44 ± 0.20	14.56 ± 2.22	9.99 ± 0.26	6.20 ± 0.63	2.21 ± 0.06	2.04 ± 0.14	4.66 ± 0.25	2.98 ± 0.15	187.22 ± 18.95
CUM 44	5.89 ± 0.70	14.11 ± 2.41	10.33 ± 0.73	7.28 ± 0.17	2.36 ± 0.05	2.10 ± 0.04	5.28 ± 0.26	3.27 ± 0.39	283.89 ± 20.02
CUM 45	4.89 ± 0.19	13.00 ± 3.05	10.38 ± 0.94	7.49 ± 0.75	2.52 ± 0.07	2.18 ± 0.13	6.03 ± 0.75	3.84 ± 0.21	290.56 ± 40.73
CUM 46	5.56 ± 0.51	9.55 ± 2.12	8.29 ± 0.15	5.16 ± 0.76	1.82 ± 0.05	1.63 ± 0.18	4.91 ± 0.77	2.67 ± 0.26	146.67 ± 6.66
CUM 47	5.78 ± 0.51	14.56 ± 2.72	10.42 ± 0.67	8.10 ± 0.63	2.40 ± 0.18	2.21 ± 0.11	5.33 ± 0.35	3.51 ± 0.02	343.89 ± 45.16
CUM 48	5.67 ± 0.33	15.33 ± 2.61	10.56 ± 0.13	8.73 ± 0.97	2.41 ± 0.12	2.28 ± 0.02	5.17 ± 0.26	3.64 ± 0.22	341.67 ± 29.48
CUM 49	5.56 ± 0.77	14.34 ± 2.52	8.84 ± 0.56	6.58 ± 0.99	2.13 ± 0.10	1.98 ± 0.07	4.42 ± 0.23	2.84 ± 0.04	255.56 ± 39.53
CUM 50	5.89 ± 1.50	10.44 ± 1.93	8.68 ± 0.29	5.52 ± 0.56	2.07 ± 0.15	1.75 ± 0.09	5.02 ± 0.33	2.58 ± 0.08	149.44 ± 40.32
Mean	5.18	14.75	9.99	7.15	2.36	2.15	5.30	3.24	329.07
Range	3 – 9	3 – 47	2.50 - 15.17	1.40 - 12.07	0.82 - 3.36	0.66 - 3.08	2.8 - 9.6	1.37 - 6.11	30 – 1230
	0.46	2.10	0.74	1.02	0.16	0.18	0.49	0.38	92.62

SD									
CV	8.88	14.24	7.41	14.27	6.78	8.37	9.25	11.73	28.15
CD @ 5%	0.95	4.04	1.22	1.57	0.27	0.28	0.88	0.48	134.30

**: significant at 1% level

Table 4.4. Genotypic variance, phenotypic variance, GCV, PCV, heritability and genetic advance in the case of the growth and yield characters of *Curcuma amada* Roxb.

	Characters	Geno-typic variance	Pheno-typic variance	GCV	PCV	Herita-bility	Genetic advance
1	Plant height	235.13	288.61	16.26	18.02	81.47	30.23
2	Number of tillers	0.06	0.12	18.60	27.13	50.00	27.95
3	Number of leaves per tiller	0.36	1.10	6.10	12.30	32.72	8.30
4	Leaf length	26.62	36.37	12.73	14.87	73.19	22.42
5	Leaf breadth	0.62	1.25	8.57	12.15	49.60	12.41
6	Leaf area	2652.36	4187.25	19.89	24.99	63.34	32.60
7	Number of primary fingers	0.10	0.44	6.18	12.74	22.72	5.96
8	Number of secondary fingers	2.36	8.49	10.44	19.73	27.80	11.30
9	Length of primary fingers	0.36	0.92	6.00	9.60	39.13	7.75
10	Length of secondary fingers	0.72	1.65	11.89	17.90	43.64	16.09
11	Diameter of primary fingers	0.02	0.05	5.94	9.32	40.00	7.68
12	Diameter of secondary fingers	0.02	0.05	6.51	10.23	40.00	8.43

13	Length of mother rhizome	0.14	0.43	6.98	12.45	32.56	8.35
14	Diameter of mother rhizome	0.12	0.21	10.80	14.19	57.14	16.71
15	Yield per plant	6323.60	13087.51	24.17	34.76	48.32	34.60

4.1.1.2.3. Genetic advance under selection

The quantum of improvement that is possible under selection can be calculated as genetic advance (Allard, 1960). It is the ratio between genotypic variance and phenotypic variance. Fifteen agronomic characters of *Curcuma amada* have been analyzed presently for genetic advance (Table 4.4). The highest genetic advance was shown by leaf area (32.60%) in the case of growth characters and yield per plant (34.60%) in the case of yield characters. Plant height also showed comparatively high genetic advance (30.23%). Number of tillers showed genetic advance of 27.95% and the lowest genetic advance was shown by number of primary fingers (5.96%). Information on genetic advance in crops like cardamom (Radhakrishnan *et al.*, 2006a), coffee (Nikhila, 2007), vanilla (Umamaheshwari, 2008), etc. have been generated by earlier workers using similar tools. However, such information in *Curcuma amada* seems to be new.

4.1.2. Correlation of characters

Most of the agronomic characters of crop plants are polygenic. These characters show different levels of correlation between them due to sharing of genes. Correlation between fifteen agronomic characters of *Curcuma amada* including six growth characters and nine yield characters has been analyzed presently based on data collected from fifty accessions of the plant (Tables 3.1 and 4.5).

Correlation analysis revealed that among the growth characters leaf area is showing significant positive correlation with twelve characters, leaf breadth is showing significant positive correlation with twelve characters, leaf length is showing significant positive correlation with eleven characters, plant height is showing significant positive correlation with eleven characters, number of leaves per tiller is showing significant positive correlation with three characters and number of tillers is showing significant positive correlation with one character (Tables 4.5. and 4.6).

Among the yield characters length of secondary fingers shows significant positive correlation with twelve characters, number of primary fingers shows significant positive correlation with four characters, length and diameter of primary fingers show significant positive correlation with eleven characters, number and diameter of secondary fingers show positive correlation with eleven characters, length of mother rhizome shows significant positive correlation with eleven characters, diameter of mother rhizome shows significant positive correlation with ten characters and yield per plant shows significant positive correlation with eleven characters.

Yield per plant shows significant positive correlation with plant height, leaf length, leaf breadth, leaf area, number of secondary fingers, length of primary fingers, length of secondary fingers, diameter of primary fingers, diameter of secondary fingers, length of mother rhizome and diameter of mother rhizome. However yield per plant did not show significant positive correlation with number of tillers, number of leaves per tiller and number of primary fingers (Tables 4.5 and 4.6).

Table 4.5. Correlation of characters in *Curcuma amada* Roxb.

Character	Plant height	Number of tillers	Number of leaves per tiller	Leaf length	Leaf breadth	Leaf area	Number of primary fingers	Number of secondary fingers	Length of primary fingers	Length of secondary fingers	Diameter of primary fingers	Diameter of secondary fingers	Length of mother rhizome	Diameter of mother rhizome
Plant height	1													
Number of tillers	-0.56236	1												
Number of leaves per tiller	0.619781**	-0.70361	1											
Leaf length	0.960067**	-0.4537	0.604289**	1										
Leaf breadth	0.492863**	0.104229	0.207718	0.637704**	1									
Leaf area	0.826145**	-0.22866	0.46848**	0.921439**	0.87768**	1								
Number of primary fingers	-0.33296	0.595275**	-0.27694	-0.22255	0.330785*	0.030197	1							
Number of secondary fingers	0.405913**	0.18827	0.073404	0.512051**	0.536719**	0.563532**	0.242762	1						
Length of primary fingers	0.430224**	-0.12075	0.167616	0.491815**	0.411421**	0.468931**	0.047511	0.685117**	1					
Length of secondary fingers	0.350428*	0.186197	0.025341	0.45008**	0.627918**	0.547567**	0.288462*	0.565351**	0.632153**	1				
Diameter of primary fingers	0.53206**	-0.20549	0.224114	0.560228**	0.372213**	0.497372**	-0.10534	0.549723**	0.725608**	0.599512**	1			
Diameter of secondary fingers	0.554219**	-0.07611	0.176111	0.608321**	0.573993**	0.628043**	0.078305	0.656008**	0.761285**	0.810957**	0.841538**	1		
Length of mother rhizome	0.564102**	-0.09742	0.242155	0.642346**	0.675804**	0.709645**	0.085997	0.48417**	0.487198**	0.57255**	0.504718**	0.533431**	1	
Diameter of mother rhizome	0.13136	0.226889	-0.12221	0.228877	0.534932**	0.370298**	0.278162*	0.340275*	0.404787**	0.777282**	0.513681**	0.634084**	0.603269**	1
Yield per plant	0.661673**	-0.02501	0.243659	0.769406**	0.723947**	0.807331**	0.102064	0.719698**	0.649193**	0.783626**	0.716005**	0.810212**	0.658756**	0.558815**

*: significant at 5% level; **: significant at 1% level

Table. 4.6. Characters that show significant positive correlation in *Curcuma amada* Roxb.

Character	Number of characters showing significant positive correlation	Characters correlated
Plant height	11	Number of leaves per tiller, Leaf length, Leaf breadth, Leaf area, Number of secondary fingers, Length of primary fingers, Length of secondary fingers, Diameter of primary fingers, Diameter of secondary fingers, Length of mother rhizome, Yield per plant
Number of tillers	1	Number of primary fingers
Number of leaves per tiller	3	Plant height, Leaf length, Leaf area
Leaf length	11	Plant height, Number of leaves per tiller, Leaf breadth, Leaf area, Number of secondary fingers, Length of primary fingers, Length of secondary fingers, Diameter of primary fingers, Diameter of secondary fingers, Length of mother rhizome, Yield per plant
Leaf breadth	12	Plant height, Leaf length, Leaf area, Number of primary fingers, Number of secondary fingers, Length of primary fingers, Length of secondary fingers, Diameter of primary fingers, Diameter of secondary fingers, Length of mother rhizome, Diameter of mother rhizome, Yield per plant
Leaf area	12	Plant height, Number of leaves per tiller, Leaf length, Leaf breadth, Number of secondary fingers, Length of primary fingers, Length of secondary fingers, Diameter of primary fingers, Diameter of secondary fingers, Length of mother rhizome, Diameter of mother rhizome, Yield per plant
Number of primary fingers	4	Number of tillers, Leaf breadth, Length of secondary fingers, Diameter of mother rhizome

Number of secondary fingers	11	Plant height, Leaf length, Leaf breadth, Leaf area, Length of primary fingers, Length of secondary fingers, Diameter of primary fingers, Diameter of secondary fingers, Length of mother rhizome, Diameter of mother rhizome, Yield per plant
Length of primary fingers	11	Plant height, Leaf length, Leaf breadth, Leaf area, Number of secondary fingers, Length of secondary fingers, Diameter of primary fingers, Diameter of secondary fingers, Length of mother rhizome, Diameter of mother rhizome, Yield per plant
Length of secondary fingers	12	Plant height, Leaf length, Leaf breadth, Leaf area, Number of primary fingers, Number of secondary fingers, Length of primary fingers, Diameter of primary fingers, Diameter of secondary fingers, Length of mother rhizome, Diameter of mother rhizome, Yield per plant
Diameter of primary fingers	11	Plant height, Leaf length, Leaf breadth, Leaf area, Number of secondary fingers, Length of primary fingers, Length of secondary fingers, Diameter of secondary fingers, Length of mother rhizome, Diameter of mother rhizome, Yield per plant
Diameter of secondary fingers	11	Plant height, Leaf length, Leaf breadth, Leaf area, Number of secondary fingers, Length of primary fingers, Length of secondary fingers, Diameter of primary fingers, Length of mother rhizome, Diameter of mother rhizome, Yield per plant
Length of mother rhizome	11	Plant height, Leaf length, Leaf breadth, Leaf area, Number of secondary fingers, Length of primary fingers, Length of secondary fingers, Diameter of primary fingers, Diameter of secondary fingers, Diameter of mother rhizome, Yield per plant
Diameter of mother rhizome	10	Leaf breadth, Leaf area, Number of primary fingers, Number of secondary fingers, Length of primary fingers, Length of secondary fingers, Diameter of primary fingers, Diameter of secondary fingers, Length of mother rhizome, Yield per plant
Yield per plant	11	Plant height, Leaf length, Leaf breadth, Leaf area, Number of secondary fingers, Length of primary fingers, Length of secondary fingers, Diameter of primary fingers, Diameter of secondary fingers, Length of mother rhizome, Diameter of mother rhizome

Studies on correlation analysis in *Curcuma amada* did not come across during literature study by the present author. However studies on correlation of agronomic characters in other species of *Curcuma* have been carried out by earlier workers. In turmeric, Raveendra *et al*. (2001) found that yield of rhizome was positively correlated with plant height, leaf area, weight of mother rhizome and weight of primary fingers. A study by Panja *et al*. (2002) showed that in *Curcuma longa* plant height, leaf number, number of primary fingers and number and weight of secondary fingers showed significant positive correlation with each other. Number and weight of secondary rhizomes exhibited higher positive correlation with yield when compared to other characters. Plant height, leaf length, thickness of primary and secondary rhizomes and number of secondary rhizomes were found to show significant positive association with rhizome yield in *Curcuma longa* (Tomar *et al*., 2005). Manohar Rao *et al*. (2006) have observed that weight of mother rhizomes showed significant positive correlation with yield in turmeric.

The information that yield per plant is positively correlated with other characters like plant height, leaf length, leaf breadth and leaf area provides a tool to select high yielding accessions based on vegetative characters in *Curcuma amada* Roxb.

4.1.3. Character association

Polygenic characters show different levels of association due to the influence of same set of alleles on different characters. Grouping of characters based on this relationship is an effective tool to group them to different factors and to identify the lead variables so that further breeding programmes could be focussed on the lead variables selected. This type of an approach considerably reduces the bulk of variables that are being handled in crop improvement programmes.

Character association in *Curcuma amada* has been studied presently based on factor analysis using fifteen variables. Three factors contributing variations to the study population could be identified. However out of the fifteen characters, thirteen variables came under factor one and one variable under factor two. Factor three did not represent any of the variables studied presently and number of tillers did not contribute positive factor loading to any of these factors (Table 4.7).

In the 1st factor group, yield per plant had the maximum factor loading followed by leaf area and diameter of secondary fingers thus making them the lead characters in the group. The variable coming under the 2nd group was the number of leaves per tiller which had a factor loading of 0.723648 in the group. Based on this analysis it can be observed that yield per plant, leaf area, diameter of secondary fingers and number of leaves per tiller could be used as lead characters in crop improvement programmes in *Curcuma amada* (Tables 4.7, 4.8 and 4.9).

Factor I contributes 51.68% of variance and factor II contributes 19.82% of variance to the cumulative variance contributed by factors I and II (Tables 4.7 and 4.8). Even though such studies have been carried out in species of *Curcuma* like *Curcuma longa* by earlier workers, no such studies could be traced by the author in *Curcuma amada*.

Tomar *et al.* (2005) carried out studies on character association and path analysis for yield components in *Curcuma longa*. They reported that characters like plant height, leaf length and thickness of primary and secondary rhizomes showed positive association with rhizome yield and these traits might be given due emphasis while making studies in the improvement of rhizome yield of turmeric. Path coefficient analysis in *Curcuma longa* has also been carried out by Manohar Rao *et al*. (2006) and observed that selection for higher weight of

mother and finger rhizomes resulted in higher yield since the characters showed significant positive correlation.

Character association has been studied by earlier workers in other crops like cardamom (Hrideek *et al*., 2008) and coffee (Nikhila *et al*., 2008) so as to group characters based on sharing of common genes and also to find out lead characters in each group.

Table 4.7. Factor analysis in *Curcuma amada* Roxb.- Factor Loadings

Character	Factor 1	Factor 2	Factor 3
Plant height	**.763790**	.560521	-.102601
Number of tillers	-.171971	-.878606	-.170470
Number of leaves per tiller	.375267	**.723648**	-.166080
Leaf length	**.850454**	.441460	-.183840
Leaf breadth	**.780333**	-.198405	-.492624
Leaf area	**.882748**	.186554	-.387589
Number of primary fingers	**.057480**	-.725689	-.397369
Number of secondary fingers	**.721739**	-.269082	.061005
Length of primary fingers	**.742455**	-.110263	.430118
Length of secondary fingers	**.786370**	-.426391	.115410
Diameter of primary fingers	**.775285**	.001086	.502421
Diameter of secondary fingers	**.874412**	-.162061	.324547
Length of mother rhizome	**.775790**	-.048023	-.209349
Diameter of mother rhizome	**.602434**	-.511463	.098744
Yield per plant	**.928381**	-.104211	-.007964

Table 4.8. Factor analysis in *Curcuma amada* Roxb.– Eigen values and cumulative variance

Factors	Eigen value	Percentage of total variance	Cumulative Eigen value	Cumulative percentage of variance
1	7.751370	51.67580	7.75137	51.67580
2	2.972877	19.81918	10.72425	71.49498
3	1.265214	8.43476	11.98946	79.92974

Table 4.9. Factor analysis in the case of *Curcuma amada* Roxb.- Factors identified

Factors	Characters
1	**Yield per plant**, **leaf area**, **diameter of secondary fingers**, leaf length, length of secondary fingers, leaf breadth, length of mother rhizome, diameter of primary fingers, plant height, length of primary fingers, number of secondary fingers, diameter of mother rhizome, number of primary fingers.
2	**Number of leaves per tiller**
3	Nil

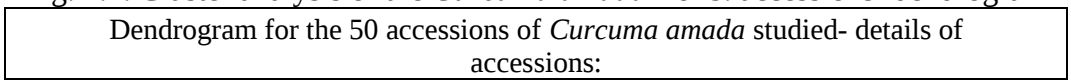
4.1.4. Genetic divergence

Different accessions of a plant species collected from different geographical areas will show different levels of interrelationship between them based on variations in characters. Genotypes that are spatially and reproductively isolated evolve in their own lines by incorporating hereditary variations interacting with the environment and also by reshuffling their genes by way of genetic recombination at the time of sexual reproduction. However, clonally propagated plants have only limited scope for variation by way of genetic recombination. In such species also variations originate by mutations and such variations get inherited into the clonal progenies and undergo selection favourably or unfavourably depending upon the merit of variation. *Curcuma amada* is a clonally propagated crop and the variations that originate by mutations get inherited through clonal progenies of each and every population.

Study of genetic divergence by cluster analysis provides an effective tool to classify genotypes based on their similarities and variations. The results of cluster analysis attempted presently in 50 accessions of *Curcuma amada* using 15 agronomic characters show that the fifty genotypes could be grouped into eight clusters at the linkage distance of 0.99 showing the genetic divergence of the genetic resources of *Curcuma amada* in Kerala (Fig. 4.1; Table 4.10). Each cluster is further branched into different sub clusters based on their interrelationships. Cluster I consists of 10 genotypes, cluster II of 6 genotypes, cluster III of 6 genotypes, cluster IV of 11 genotypes, cluster V of 5 genotypes, cluster VI of 6 genotypes, cluster VII of 4 genotypes and cluster VIII of 2 genotypes. This shows that cluster IV is the largest one with 11 genotypes and cluster VIII the smallest with 2 genotypes. The dendrogram gives an idea about the similarities and dissimilarities of the accessions studied. Accessions CUM 16 and CUM 19 were found to be the closest followed by accessions CUM 34 and CUM 35. Accessions CUM 47 and CUM 50 form a distinct cluster which shows the highest distance from the other genotypes.

The above study gives an idea of the genetic diversity of the crop. Genotypes that are distant can be used for hybridization programmes. Selection can be practiced based on the merits of the genotypes as evidenced by the study of their performance. Studies on genetic divergence have been carried out to analyze the genetic distance between different genotypes in many plants like dahlia (Misra *et al*., 1990), chilli (Pandey and Dobhal., 1993), coconut (Jayalekshmi and Sree Rangasamy., 2002), cardamom (Radhakrishnan *et al.,* 2006b), lab lab bean (Sankaran *et al*., 2008) and rice (Nair and Thomas, 2005; Panwar *et al*., 2008).

Fig. 4.1. Cluster analysis of the *Curcuma amada* Roxb. accessions- dendrogram



1: CUM 1
2: CUM 2
3: CUM 3
4: CUM 4
5: CUM 5
6: CUM 6
7: CUM 7
8: CUM 8
9: CUM 9
10: CUM 10
11: CUM 11
12: CUM 12
13: CUM 13
14: CUM 14
15: CUM 15
16: CUM 16
17: CUM 17
18: CUM 18
19: CUM 19
20: CUM 20
21: CUM 21
22: CUM 22
23: CUM 23
24: CUM 24
25: CUM 25
26: CUM 26
27: CUM 27
28: CUM 28
29: CUM 29
30: CUM 30
31: CUM 31
32: CUM 32
33: CUM 33
34: CUM 34
35: CUM 35
36: CUM 36
37: CUM 37
38: CUM 38
39: CUM 39
40: CUM 40
41: CUM 41
42: CUM 42
43: CUM 43
44: CUM 44
45: CUM 45
46: CUM 46
47: CUM 47
48: CUM 48
49: CUM 49
50: CUM 50

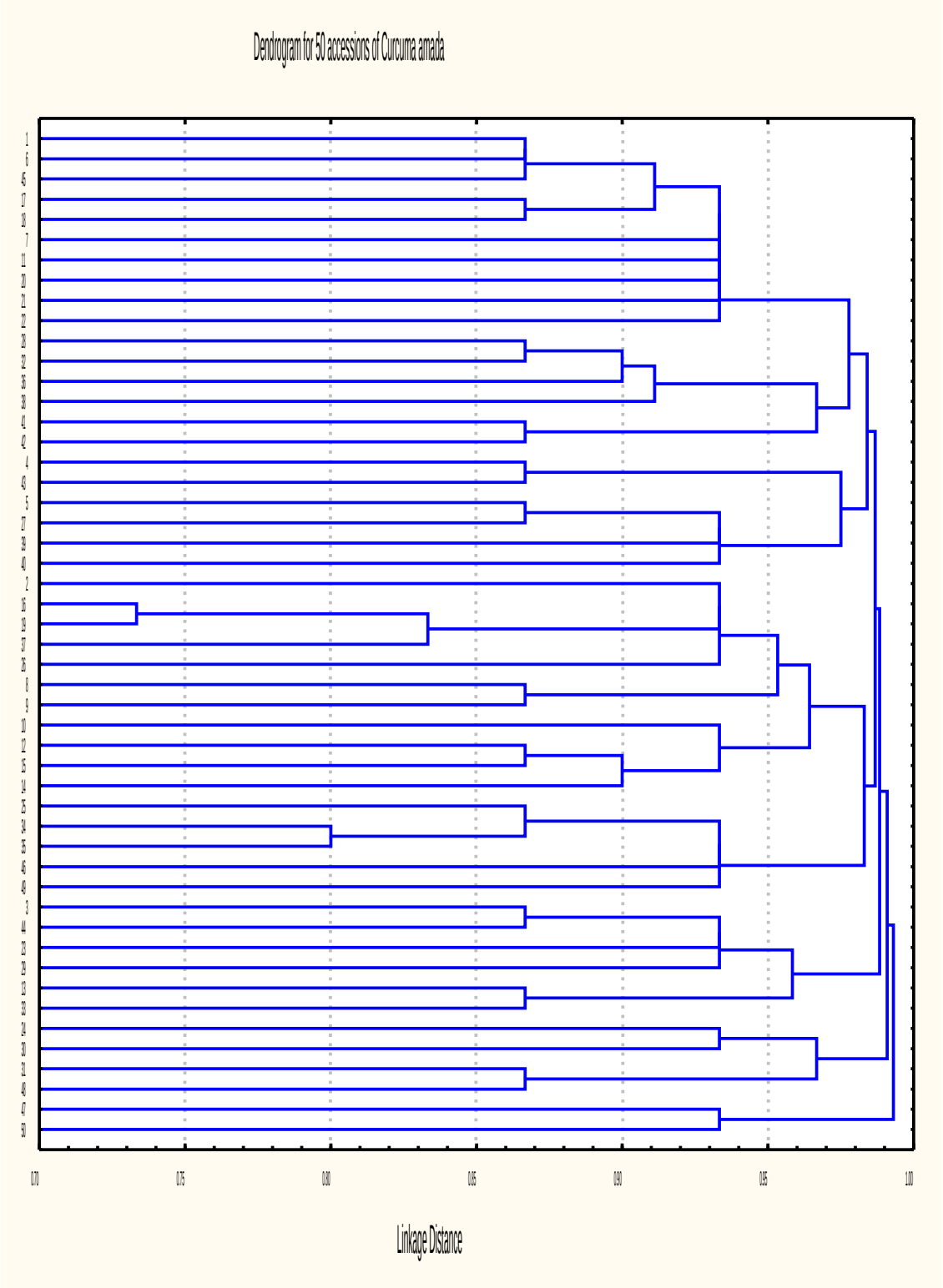


Table 4.10. Clustering of genotypes in the case of the accessions of

Curcuma amada Roxb. studied

Cluster No.	Genotypes
1	CUM 1, CUM 6, CUM 45, CUM 17, CUM 18, CUM 7, CUM 11, CUM 20, CUM 21, CUM 22
2	CUM 28, CUM 32, CUM 36, CUM 38, CUM 41, CUM 42
3	CUM 4, CUM 43, CUM 5, CUM 27, CUM 39, CUM 40
4	CUM 2, CUM 16, CUM 19, CUM 37, CUM 26, CUM 8, CUM 9, CUM 10, CUM 12, CUM 15, CUM 14
5	CUM 25, CUM 34, CUM 35, CUM 46, CUM 49
6	CUM 3, CUM 44, CUM 23, CUM 29, CUM 13, CUM 33
7	CUM 24, CUM 30, CUM 31, CUM 48
8	CUM 47, CUM 50

4.1.5. Performance analysis of *Curcuma amada* Roxb. accessions collected

A study of the overall performance of 50 accessions of *Curcuma amada* (Table 3.1) has been attempted presently based on performance index and cumulative performance index calculated as described elsewhere.

Among the 50 accessions, accession number CUM 34 ranked the highest with a cumulative performance index of 17.63 followed by CUM 35 with a cumulative performance index of 17.28 (Tables 4.11 and 4.12 and Figs. 4.2 and 4.3). The accessions CUM 33, CUM 31, CUM 36, CUM 38, CUM 2, CUM 19, CUM 3 and CUM 32 ranked from 3 – 10 respectively (Figs. 4.4 to 4.11). The superior accessions show significantly high level of agronomic characters and these accessions can be subjected to further selection procedures so that superior planting material is made available to the farmers.

Table 4.11. Performance analysis of the accessions of *Curcuma amada* Roxb. studied- character means

Acc. No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
CUM 1	98.72	1	8.67	40.3	8.76	243.24	4.44	14.44	9.57	7.02	2.27	2.03	4.97	2.7	293.89
CUM 2	117.95	1.1	9.33	50.06	10.08	350	4.55	18.44	10.8	6.68	2.55	2.24	6.61	2.89	430
CUM 3	115.5	1.33	8.22	48.17	10.17	341.69	5.11	17.78	10.89	6.6	2.47	2.24	5.4	2.86	452.22
CUM 4	112.33	1.2	9.78	49.32	10.02	340.52	5.11	17.11	10.24	7.04	2.19	1.96	5.61	2.77	415.55
CUM 5	102.33	1	8.33	41.61	9.33	268.65	5.44	13.78	9.98	7.08	2.31	2.14	5.91	3.27	314.44
CUM 6	104.89	1	8.67	43.83	8.84	268.55	4.45	15	10.69	6.65	2.32	2.13	5.77	3.29	301.11
CUM 7	94.95	1	8.56	40.63	7.85	217.49	4.33	12.67	9.06	6.37	2.22	1.97	5.1	2.89	257.22
CUM 8	93.89	1.1	9	39.78	7.81	215.58	4.78	14	9.26	5.47	2.27	1.93	4.67	2.74	242.78
CUM 9	107.11	1.23	8.78	40.81	8.38	233.59	4.78	14.89	10.35	6.44	2.27	1.97	5.07	2.78	266.67
CUM 10	104.28	1.23	9.44	41.48	8.49	244.85	4.89	13.89	9.23	7.05	2.39	2.07	5.42	3.18	353.33
CUM 11	100.17	1	9.55	41.55	8.62	245.39	4.55	12.33	10.39	7.17	2.43	2.12	4.82	2.85	265.55
CUM 12	103.11	1	9.22	43.68	8.34	248.66	4.89	15	10.26	7.18	2.37	2.16	4.7	2.83	296.67
CUM 13	109.44	1.33	8.78	43.37	8.62	256.82	5.22	14.78	10.19	6.54	2.53	2.35	4.98	2.79	323.11
CUM 14	107.5	1.1	9.11	41.61	8.46	248.72	4.89	14.11	9.37	6.63	2.3	2.18	5.11	2.93	313.33

	6														
CUM 15	112.5	1.1	8.22	45.46	8.98	283.36	4.89	12.33	9.82	7.18	2.59	2.2	5.27	3.34	387.78
CUM 16	107.11	1.1	8.89	42.79	9.04	265.76	5	14.33	10.08	7.59	2.23	2.27	5.34	3.25	312.78
CUM 17	115.61	1	9.22	46.89	9.53	309.12	5.22	16.89	10.48	7.71	2.52	2.22	5.7	3.53	420
CUM 18	114.44	1	9.22	47.62	9.64	310.61	4.56	13	10.23	8.28	2.51	2.38	5.72	3.71	386.67
CUM 19	107.11	1.1	8.89	45.49	9.92	311.52	5	16.66	10.53	8.11	2.62	2.39	5.17	3.16	549.44
CUM 20	88.72	1	8.34	39	8.41	225.02	5	14.56	10.88	7.34	2.44	2.24	5.49	3.19	305.55
CUM 21	101.61	1	9.67	43.94	8.86	255.14	5.11	16.78	11.35	8.45	2.57	2.4	5.35	3.82	455.56
CUM 22	91.39	1	8.44	38.7	8.3	219.72	4.11	12.78	9.63	5.49	2.47	2.1	4.62	2.98	229.45
CUM 23	87.52	1.33	8.11	37.89	9.25	239.1	4.55	13.11	9.41	7.41	2.27	2.16	4.94	3.32	277.22
CUM 24	80.67	1.7	7.56	35.57	8.63	211.01	5.67	17.89	9.71	6.36	2.38	2.12	5.3	3.17	259.44
CUM 25	86.72	1.1	8.89	37.72	9.02	231.88	5.56	15.89	10.76	6.56	2.47	2.22	5.04	3.13	307.22
CUM 26	82.78	1.1	7.78	34.77	8.62	205.54	4.22	11.33	9.08	5.18	2.31	1.92	4.9	3.07	192.78
CUM 27	90.28	1.43	8.33	38.61	9.68	254.46	5.44	16.11	9.91	7.35	2.43	2.17	5.4	3.48	326.11
CUM 28	89.55	1.43	8.11	39.03	9.64	257.8	5.33	15.89	9.73	7.54	2.3	2.27	5.03	3.41	374.44
CUM 29	63.72	1.33	8.44	30.34	7.36	156.58	5.33	9.55	7.42	4.61	1.93	1.68	4.27	2.81	150
CUM 30	75.12	1.8	7.78	37.13	9.49	242.48	5	15.11	10.16	7.05	2.4	2.12	5.36	3.63	363.89
CUM 31	107.83	1.43	8.45	46.96	10.29	319.76	5.67	16.66	10.53	8.73	2.6	2.35	6.05	3.77	468.33
CUM 32	114.06	1	10.22	48.64	10.88	361.81	5.33	15.67	9.78	7.54	2.35	2.2	5.65	3.26	377.22
CUM 33	111.28	1.2	8.78	48.4	11.61	397.45	5.89	16.22	10.81	8.64	2.53	2.46	5.57	3.61	441.67
CUM 34	110.5	1.43	9.22	48.33	11.41	375.3	5.56	18.56	9.82	8.87	2.47	2.39	6.17	3.83	494.44
CUM 35	114	1.43	8.67	48.69	10.88	362.62	5.56	17.67	10.6	8.03	2.47	2.34	6.16	3.84	450

CUM 36	109.11	1.43	8.78	46.59	11.01	350.86	5.33	13.56	9.8	8.26	2.32	2.24	6.16	4.12	406.11
CUM 37	96.72	1.1	9.22	41.84	10.06	290.6	5	13.66	10.53	7.76	2.39	2.21	5.45	3.28	390
CUM 38	89.45	1.9	7.44	41.37	9.96	280.99	5.33	17.56	10.96	8.85	2.35	2.28	5.44	3.52	458.33
CUM 39	73.67	1.43	8	35.35	9.07	218.61	5.78	15.34	10.33	7.02	2.31	2.09	4.87	3.25	300
CUM 40	77.89	1.7	6.89	35.33	8.94	226.3	5.44	16.44	10.28	7.42	2.26	2.18	4.89	3.25	273.33
CUM 41	80.28	1.8	7.33	36.11	9.19	225.84	5.55	15	9.45	8.45	2.43	2.13	5.49	3.9	336.11
CUM 42	71.55	1.67	7.33	33.06	8.66	194.89	5.33	15	9.87	6.69	2.21	1.97	5.09	3.24	235
CUM 43	78.61	1.2	9.78	34.9	9.2	220.28	5.44	14.56	9.99	6.2	2.21	2.04	4.66	2.98	187.22
CUM 44	74.83	1.33	8.22	34.81	8.46	200.29	5.89	14.11	10.33	7.28	2.36	2.1	5.28	3.27	283.89
CUM 45	80.56	1	8.67	35.5	8.73	210.93	4.89	13	10.38	7.49	2.52	2.18	6.03	3.84	290.56
CUM 46	77.61	1.3	7.44	33.35	9.03	206.93	5.56	9.55	8.29	5.16	1.82	1.63	4.91	2.67	146.67
CUM 47	78.56	1.67	7.45	34.39	9.26	217.62	5.78	14.56	10.42	8.1	2.4	2.21	5.33	3.51	343.89
CUM 48	72.5	1.9	7.22	32.76	8.87	198.43	5.67	15.33	10.56	8.73	2.41	2.28	5.17	3.64	341.67
CUM 49	64.11	1.9	7.11	31.84	8.55	187.19	5.56	14.34	8.84	6.58	2.13	1.98	4.42	2.84	255.56
CUM 50	65.83	1.67	9	32.3	8.93	199.12	5.89	10.44	8.68	5.52	2.07	1.75	5.02	2.58	149.44
Mean	94.32	1.29	8.53	40.55	9.22	258.97	5.16	14.75	9.97	7.20	2.53	2.34	5.30	3.24	329.07

1: Plant height (cm); 2: Number of tillers; 3: Number of leaves per tiller; 4: Leaf length (cm); 5: Leaf breadth (cm); 6: Leaf area (cm^2); 7: Number of primary fingers; 8: Number of secondary fingers; 9: Length of primary fingers (cm); 10: Length of secondary fingers (cm); 11: Diameter of primary fingers (cm); 12: Diameter of secondary fingers (cm); 13: Length of mother rhizome (cm); 14: Diameter of mother rhizome (cm); 15:Yield per plant (g).

Table 4.12. Performance analysis of the accessions of *Curcuma amada* Roxb. studied- performance indices

Acc. No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Total	Rank of perfor-mance
CUM 1	1.05	0.78	1.02	0.99	0.95	0.94	0.86	0.98	0.96	0.98	0.90	0.87	0.94	0.83	0.89	13.94	39
CUM 2	**1.25**	**0.85**	**1.09**	**1.23**	**1.09**	**1.35**	**0.88**	**1.25**	**1.08**	**0.93**	**1.01**	**0.96**	**1.25**	**0.89**	**1.31**	**16.42**	**7**
CUM 3	**1.22**	**1.03**	**0.96**	**1.19**	**1.10**	**1.32**	**0.99**	**1.21**	**1.09**	**0.92**	**0.98**	**0.96**	**1.02**	**0.88**	**1.37**	**16.2**	**9**

																4	
CUM 4	1.19	0.93	1.15	1.22	1.09	1.31	0.99	1.16	1.03	0.98	0.87	0.84	1.06	0.85	1.26	15.93	13
CUM 5	1.08	0.78	0.98	1.03	1.01	1.04	1.05	0.93	1.00	0.98	0.91	0.91	1.12	1.01	0.96	14.79	25
CUM 6	1.11	0.78	1.02	1.08	0.96	1.04	0.86	1.02	1.07	0.92	0.92	0.91	1.09	1.02	0.92	14.72	27
CUM 7	1.01	0.78	1.00	1.00	0.85	0.84	0.84	0.86	0.91	0.88	0.88	0.84	0.96	0.89	0.78	13.32	44
CUM 8	1.00	0.85	1.06	0.98	0.85	0.83	0.93	0.95	0.93	0.76	0.90	0.82	0.88	0.85	0.74	13.33	43
CUM 9	1.14	0.95	1.03	1.01	0.91	0.90	0.93	1.01	1.04	0.89	0.90	0.84	0.96	0.86	0.81	14.18	36
CUM 10	1.11	0.95	1.11	1.02	0.92	0.95	0.95	0.94	0.93	0.98	0.94	0.88	1.02	0.98	1.07	14.75	26
CUM 11	1.06	0.78	1.12	1.02	0.93	0.95	0.88	0.84	1.04	1.00	0.96	0.91	0.91	0.88	0.81	14.09	38
CUM 12	1.09	0.78	1.08	1.08	0.90	0.96	0.95	1.02	1.03	1.00	0.94	0.92	0.89	0.87	0.90	14.41	31
CUM 13	1.16	1.03	1.03	1.07	0.93	0.99	1.01	1.00	1.02	0.91	1.00	1.00	0.94	0.86	0.98	14.93	23
CUM 14	1.14	0.85	1.07	1.03	0.92	0.96	0.95	0.96	0.94	0.92	0.91	0.93	0.96	0.90	0.95	14.39	32
CUM 15	1.19	0.85	0.96	1.12	0.97	1.09	0.95	0.84	0.98	1.00	1.02	0.94	0.99	1.03	1.18	15.11	19
CUM 16	1.14	0.85	1.04	1.06	0.98	1.03	0.97	0.97	1.01	1.05	0.88	0.97	1.01	1.00	0.95	14.91	24
CUM 17	1.23	0.78	1.08	1.16	1.03	1.19	1.01	1.15	1.05	1.07	1.00	0.95	1.08	1.09	1.28	16.15	11
CUM 18	1.21	0.78	1.08	1.17	1.05	1.20	0.88	0.88	1.03	1.15	0.99	1.02	1.08	1.15	1.18	15.8	14

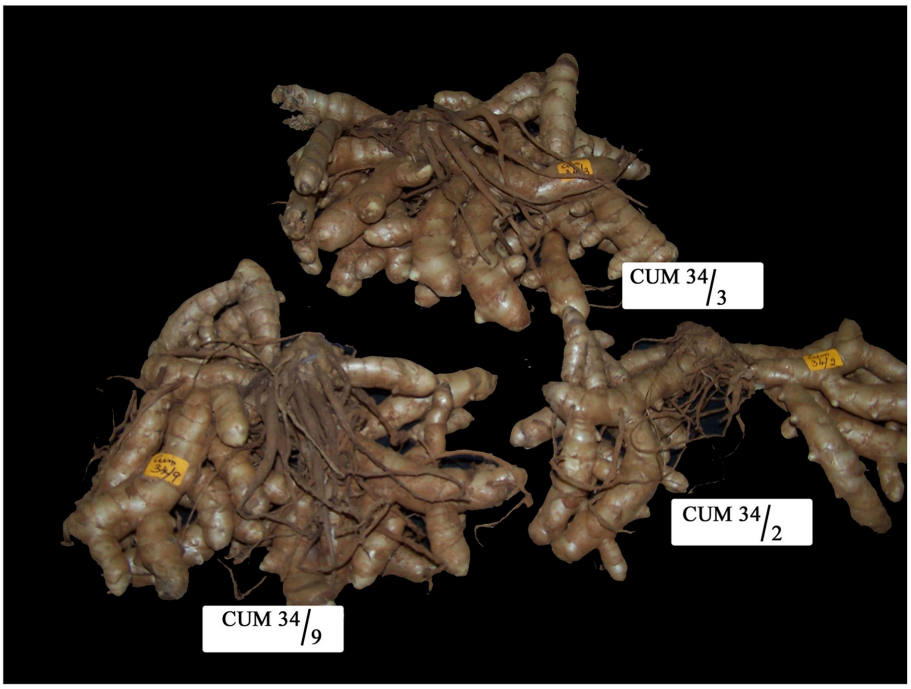
																5	
CUM 19	**1.14**	**0.85**	**1.04**	**1.12**	**1.08**	**1.20**	**0.97**	**1.13**	**1.06**	**1.13**	**1.04**	**1.02**	**0.98**	**0.98**	**1.67**	**16.41**	**8**
CUM 20	0.94	0.78	0.98	0.96	0.91	0.87	0.97	0.99	1.09	1.02	0.96	0.96	1.04	0.98	0.93	14.38	33
CUM 21	1.08	0.78	1.13	1.08	0.96	0.99	0.99	1.14	1.14	1.17	1.02	1.03	1.01	1.18	1.38	16.08	12
CUM 22	0.97	0.78	0.99	0.95	0.90	0.85	0.80	0.87	0.97	0.76	0.98	0.90	0.87	0.92	0.70	13.21	45
CUM 23	0.93	1.03	0.95	0.93	1.00	0.92	0.88	0.89	0.94	1.03	0.90	0.92	0.93	1.02	0.84	14.11	37
CUM 24	0.86	1.32	0.89	0.88	0.94	0.81	1.10	1.21	0.97	0.88	0.94	0.91	1.00	0.98	0.79	14.48	29
CUM 25	0.92	0.85	1.04	0.93	0.98	0.90	1.08	1.08	1.08	0.91	0.98	0.95	0.95	0.97	0.93	14.55	28
CUM 26	0.88	0.85	0.91	0.86	0.93	0.79	0.82	0.77	0.91	0.72	0.91	0.82	0.92	0.95	0.59	12.63	47
CUM 27	0.96	1.11	0.98	0.95	1.05	0.98	1.05	1.09	0.99	1.02	0.96	0.93	1.02	1.07	0.99	15.15	18
CUM 28	0.95	1.11	0.95	0.96	1.05	1.00	1.03	1.08	0.98	1.05	0.91	0.97	0.95	1.05	1.14	15.18	17
CUM 29	0.68	1.03	0.99	0.75	0.80	0.60	1.03	0.65	0.74	0.64	0.76	0.72	0.81	0.87	0.46	11.53	49
CUM 30	0.80	1.40	0.91	0.92	1.03	0.94	0.97	1.02	1.02	0.98	0.95	0.91	1.01	1.12	1.11	15.09	21
CUM 31	**1.14**	**1.11**	**0.99**	**1.16**	**1.12**	**1.23**	**1.10**	**1.13**	**1.06**	**1.21**	**1.03**	**1.00**	**1.14**	**1.16**	**1.42**	**17.00**	**4**
CUM 32	**1.21**	**0.78**	**1.20**	**1.20**	**1.18**	**1.40**	**1.03**	**1.06**	**0.98**	**1.05**	**0.93**	**0.94**	**1.07**	**1.01**	**1.15**	**16.19**	**10**
CUM 33	**1.18**	**0.93**	**1.03**	**1.19**	**1.26**	**1.53**	**1.14**	**1.10**	**1.08**	**1.20**	**1.00**	**1.05**	**1.05**	**1.11**	**1.34**	**17.1**	**3**

																9	
CUM 34	**1.17**	**1.11**	**1.08**	**1.19**	**1.24**	**1.45**	**1.08**	**1.26**	**0.98**	**1.23**	**0.98**	**1.02**	**1.16**	**1.18**	**1.50**	**17.63**	**1**
CUM 35	**1.21**	**1.11**	**1.02**	**1.20**	**1.18**	**1.40**	**1.08**	**1.20**	**1.06**	**1.12**	**0.98**	**1.00**	**1.16**	**1.19**	**1.37**	**17.28**	**2**
CUM 36	**1.16**	**1.11**	**1.03**	**1.15**	**1.19**	**1.35**	**1.03**	**0.92**	**0.98**	**1.15**	**0.92**	**0.96**	**1.16**	**1.27**	**1.23**	**16.61**	**5**
CUM 37	1.03	0.85	1.08	1.03	1.09	1.12	0.97	0.93	1.06	1.08	0.94	0.94	1.03	1.01	1.19	15.35	15
CUM 38	**0.95**	**1.47**	**0.87**	**1.02**	**1.08**	**1.09**	**1.03**	**1.19**	**1.10**	**1.23**	**0.93**	**0.97**	**1.03**	**1.09**	**1.39**	**16.44**	**6**
CUM 39	0.78	1.11	0.94	0.87	0.98	0.84	1.12	1.04	1.04	0.98	0.91	0.89	0.92	1.00	0.91	14.33	35
CUM 40	0.83	1.32	0.81	0.87	0.97	0.87	1.05	1.11	1.03	1.03	0.89	0.93	0.92	1.00	0.83	14.46	30
CUM 41	0.85	1.40	0.86	0.89	1.00	0.87	1.08	1.02	0.95	1.17	0.96	0.91	1.04	1.20	1.02	15.22	16
CUM 42	0.76	1.29	0.86	0.82	0.94	0.75	1.03	1.02	0.99	0.93	0.87	0.84	0.96	1.00	0.71	13.77	40
CUM 43	0.83	0.93	1.15	0.86	1.00	0.85	1.05	0.99	1.00	0.86	0.87	0.87	0.88	0.92	0.57	13.63	41
CUM 44	0.79	1.03	0.96	0.86	0.92	0.77	1.14	0.96	1.04	1.01	0.93	0.90	1.00	1.01	0.86	14.18	36
CUM 45	0.85	0.78	1.02	0.88	0.95	0.81	0.95	0.88	1.04	1.04	1.00	0.93	1.14	1.19	0.88	14.34	34
CUM 46	0.82	1.01	0.87	0.82	0.98	0.80	1.08	0.65	0.83	0.72	0.72	0.70	0.93	0.82	0.45	12.20	48
CUM 47	0.83	1.29	0.87	0.85	1.00	0.84	1.12	0.99	1.05	1.13	0.95	0.94	1.01	1.08	1.05	15.00	22
CUM 48	0.77	1.47	0.85	0.81	0.96	0.77	1.10	1.04	1.06	1.21	0.95	0.97	0.98	1.12	1.04	15.1	20

																0	
CUM 49	0.68	1.47	0.83	0.79	0.93	0.72	1.08	0.97	0.89	0.91	0.84	0.85	0.83	0.88	0.78	13.45	42
CUM 50	0.70	1.29	1.06	0.80	0.97	0.77	1.14	0.71	0.87	0.77	0.82	0.75	0.95	0.80	0.45	12.85	46

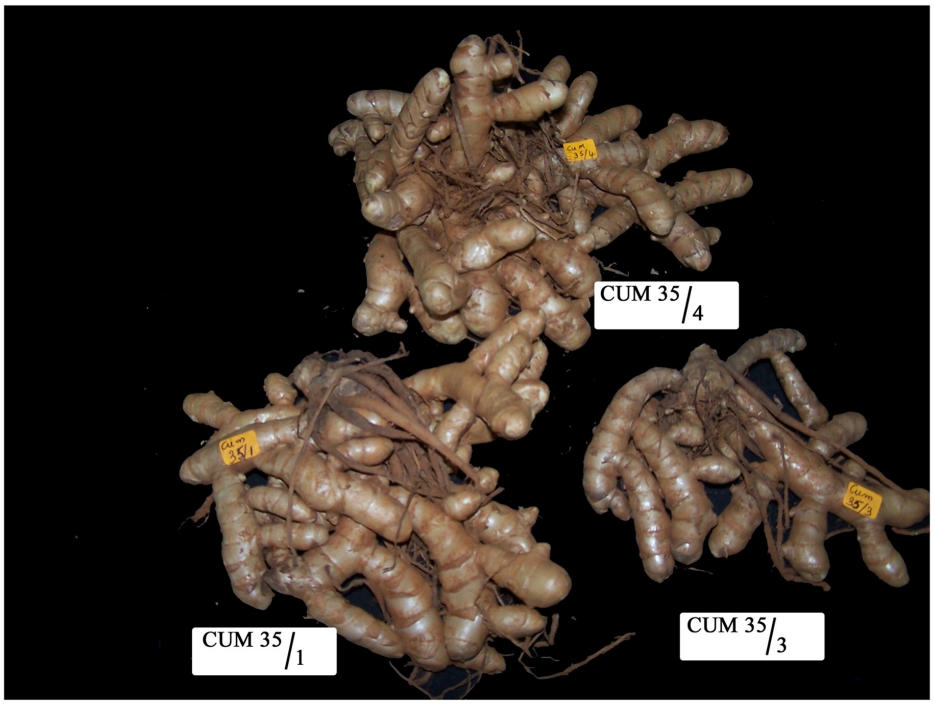
1: Plant height; 2: Number of tillers; 3: Number of leaves per tiller; 4: Leaf length; 5: Leaf breadth; 6: Leaf area; 7: Number of primary fingers; 8: Number of secondary fingers; 9: Length of primary fingers; 10: Length of secondary fingers; 11: Diameter of primary fingers; 12: Diameter of secondary fingers; 13: Length of mother rhizome; 14: Diameter of mother rhizome; 15:Yield per plant.

Fig. 4.2. Rhizome of *Curcuma amada* Roxb. Accession No. 34
Rank No. 1



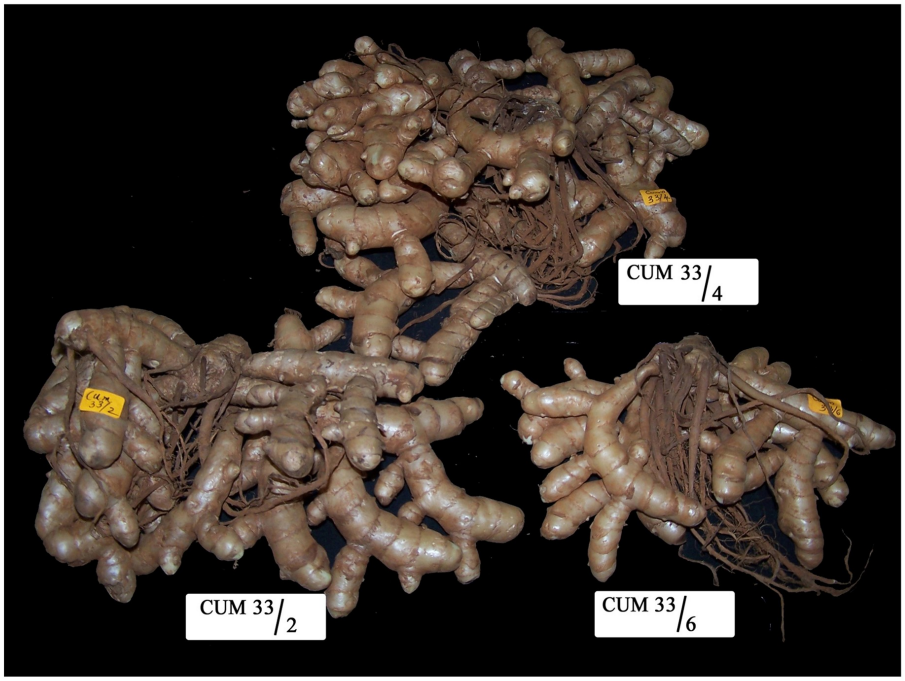
Plant height (cm)	:	110.50
Number of tillers	:	1.43
Number of leaves per tiller	:	9.22
Leaf area (cm^2)	:	375.30
Number of primary fingers	:	5.56
Number of secondary fingers	:	18.56
Yield per plant (g)	:	494.44

Fig. 4.3. Rhizome of *Curcuma amada* Roxb. Accession No. 35
Rank No. 2



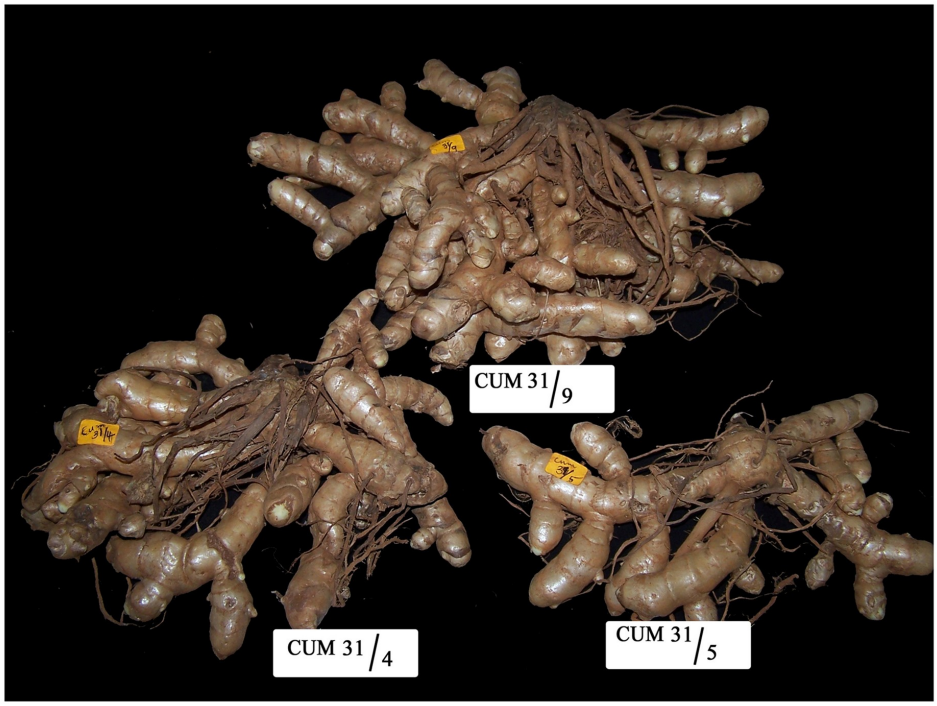
Plant height (cm)	:	114.00
Number of tillers	:	1.43
Number of leaves per tiller	:	8.67
Leaf area (cm^2)	:	362.62
Number of primary fingers	:	5.56
Number of secondary fingers	:	17.67
Yield per plant (g)	:	450.00

Fig. 4.4. Rhizome of *Curcuma amada* Roxb. Accession No. 33
Rank No. 3



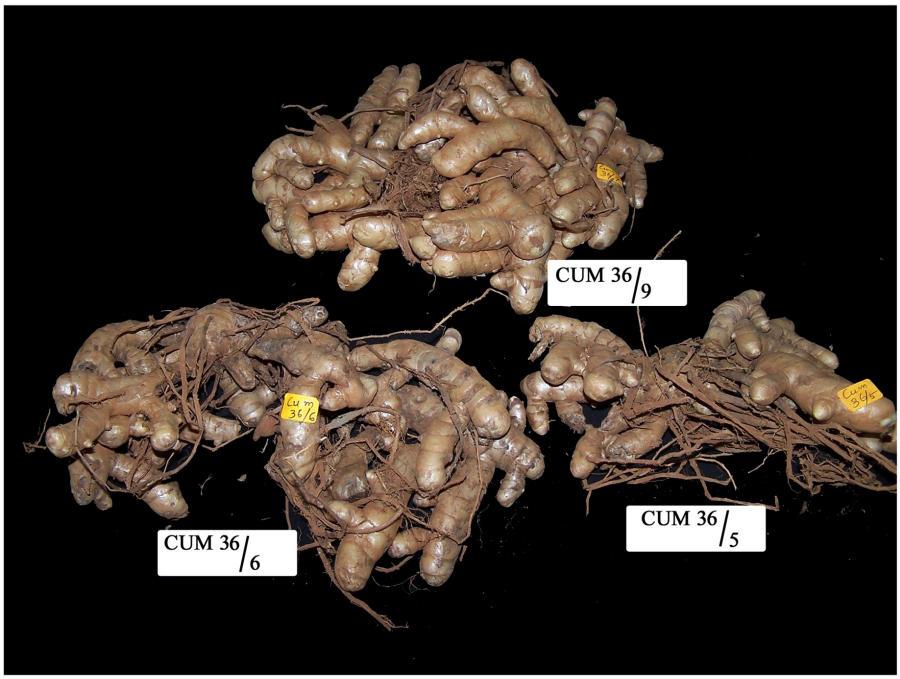
Plant height (cm)	:	111.28
Number of tillers	:	1.20
Number of leaves per tiller	:	8.78
Leaf area (cm^2)	:	397.45
Number of primary fingers	:	5.89
Number of secondary fingers	:	16.22
Yield per plant (g)	:	441.67

Fig. 4.5. Rhizome of *Curcuma amada* Roxb. Accession No. 31
Rank No. 4



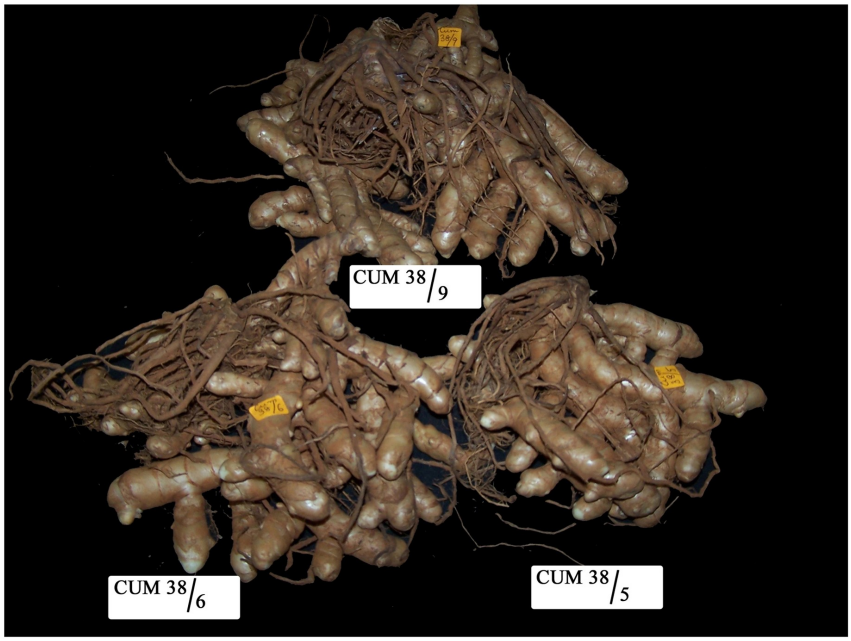
Plant height (cm)	:	107.83
Number of tillers	:	1.43
Number of leaves per tiller	:	8.45
Leaf area (cm^2)	:	319.76
Number of primary fingers	:	5.67
Number of secondary fingers	:	16.66
Yield per plant (g)	:	468.33

Fig. 4.6. Rhizome of *Curcuma amada* Roxb. Accession No. 36
Rank No. 5



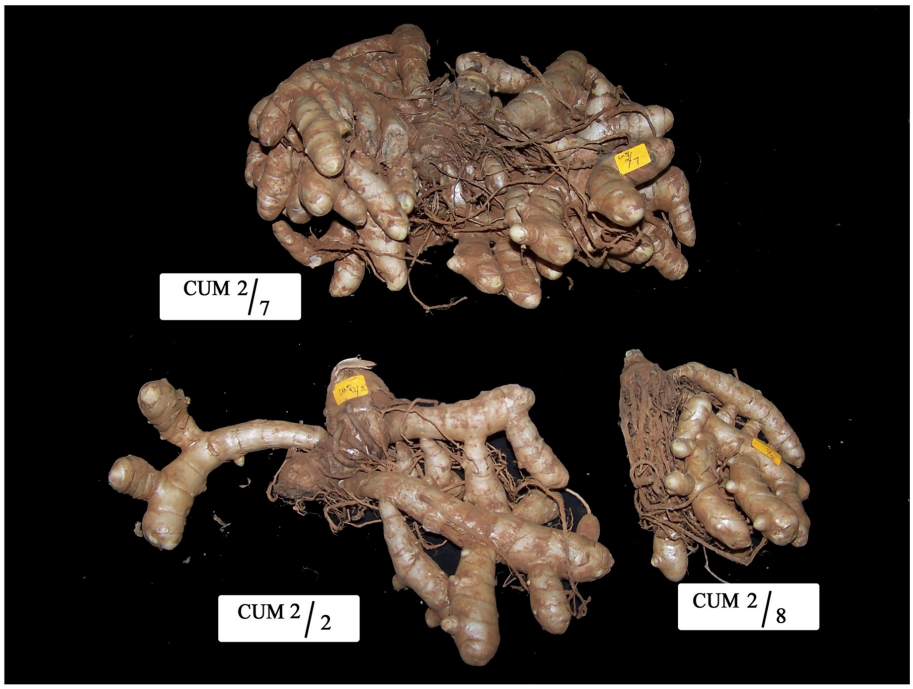
Plant height (cm)	:	109.11
Number of tillers	:	1.43
Number of leaves per tiller	:	8.78
Leaf area (cm^2)	:	350.86
Number of primary fingers	:	5.33
Number of secondary fingers	:	13.56
Yield per plant (g)	:	406.11

Fig. 4.7. Rhizome of *Curcuma amada* Roxb. Accession No. 38
Rank No. 6



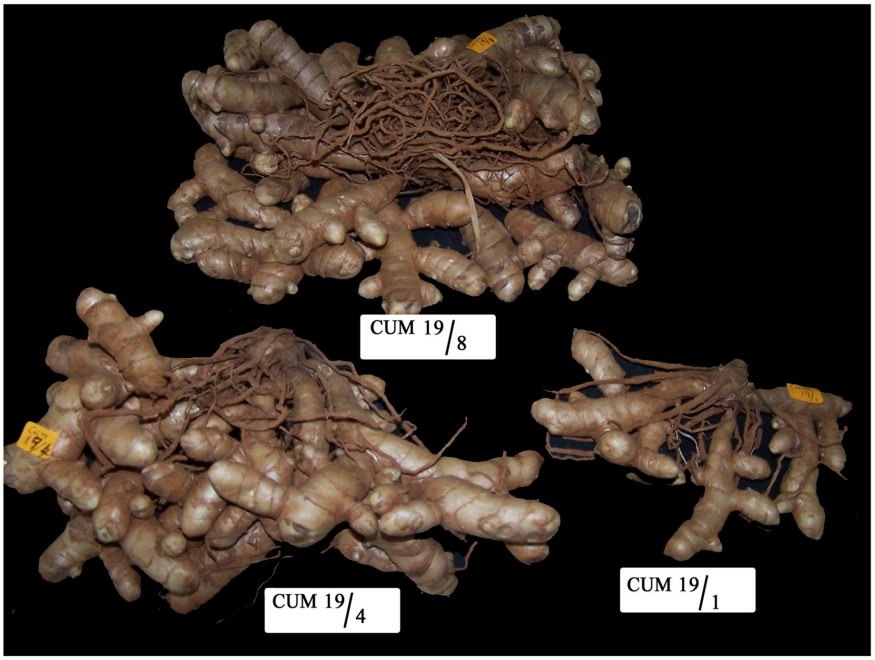
Plant height (cm)	:	89.45
Number of tillers	:	1.90
Number of leaves per tiller	:	7.44
Leaf area (cm^2)	:	280.99
Number of primary fingers	:	5.33
Number of secondary fingers	:	17.57
Yield per plant (g)	:	458.33

Fig. 4.8. Rhizome of *Curcuma amada* Roxb. Accession No. 2
Rank No. 7



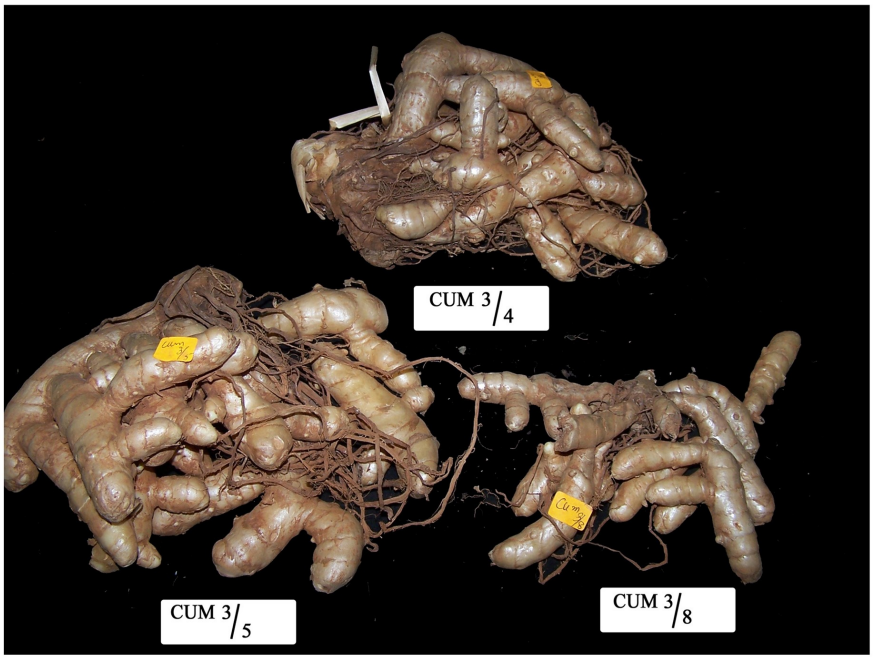
Plant height (cm)	:	117.95
Number of tillers	:	1.10
Number of leaves per tiller	:	9.33
Leaf area (cm^2)	:	350.00
Number of primary fingers	:	4.55
Number of secondary fingers	:	18.44
Yield per plant (g)	:	430.00

Fig. 4.9. Rhizome of *Curcuma amada* Roxb. Accession No. 19
Rank No. 8



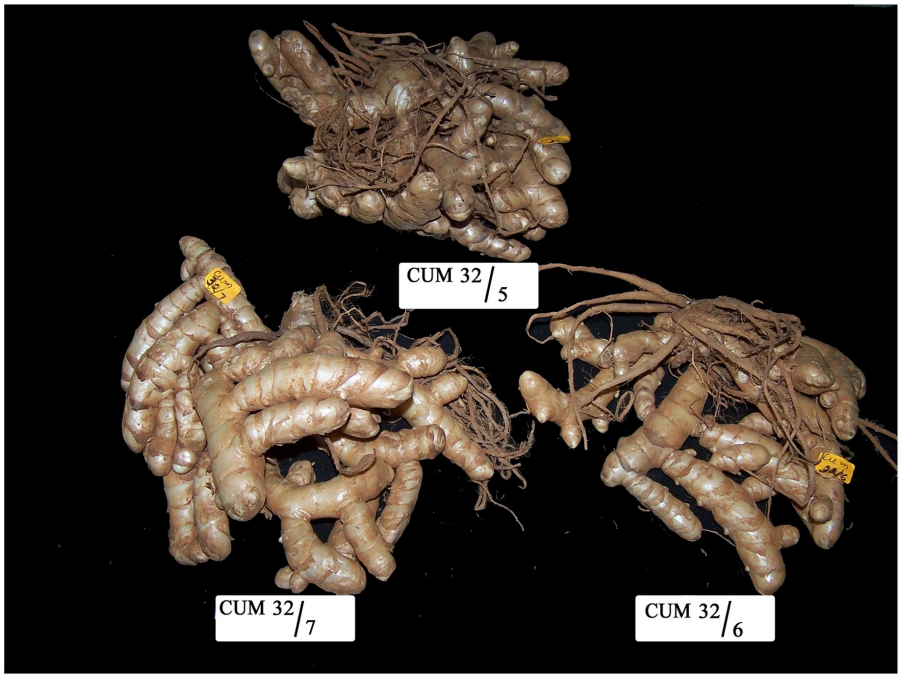
Plant height (cm)	:	107.11
Number of tillers	:	1.10
Number of leaves per tiller	:	8.89
Leaf area (cm^2)	:	311.52
Number of primary fingers	:	5.00
Number of secondary fingers	:	16.66
Yield per plant (g)	:	549.44

Fig. 4.10. Rhizome of *Curcuma amada* Roxb. Accession No. 3
Rank No. 9



Plant height (cm)	:	115.50
Number of tillers	:	1.33
Number of leaves per tiller	:	8.22
Leaf area (cm^2)	:	341.69
Number of primary fingers	:	5.11
Number of secondary fingers	:	17.78
Yield per plant (g)	:	452.22

Fig. 4.11. Rhizome of *Curcuma amada* Roxb. Accession No. 32
Rank No. 10



Plant height (cm)	:	114.06
Number of tillers	:	1.00
Number of leaves per tiller	:	10.22
Leaf area (cm^2)	:	361.81
Number of primary fingers	:	5.33
Number of secondary fingers	:	15.67
Yield per plant (g)	:	377.22

Being a marginalized crop, improvement of yield potential is very important for popularization of the crop as food component and also for product diversification. The only improved variety reported from India is Amba, which is a selection of local germplasm reported from High Altitude Research Station, Orissa University of Agriculture and Technology, Pottangi, Orissa (Johny and Ravindran, 2005). In Kerala, local cultivars are being used for cultivation and they show very high level of variability. Hence the development of improved varieties from the superior genotypes selected presently will be highly useful to the farmers.

4.1.6. Study of performance based on the status of planting materials used

In an experiment in which 150 plants of *Curcuma amada* were raised using mother rhizomes, primary fingers and secondary fingers taking 50 each as seed rhizomes to find out whether the status of the seed material selected had any role in the growth and yield of the crop. The influence of different types of planting material on sixteen growth/yield characters was observed. Out of the observed characters, only ten characters showed statistically significant variations based on the status of the planting material used (Table 4.13). The characters that showed statistically significant variations were days for germination, leaf length, leaf breadth, leaf area, number of secondary fingers , length of primary fingers, length of secondary fingers, diameter of primary fingers, diameter of mother rhizome and yield per plant.

Mean days taken for germination, plant height, leaf length, leaf breadth, leaf area, number of secondary fingers, length of primary fingers, length of secondary fingers, diameter of primary fingers, diameter of mother rhizome and yield per plant showed comparatively higher values in the case of plants produced by mother rhizome and this difference has been found to be statistically significant. Leaf length, leaf breadth, leaf area, diameter of primary fingers and

diameter of mother rhizome showed higher values in the case of plants produced from primary fingers when compared with the plants from secondary fingers. The outcome of the experiment shows that when mother rhizome is used as planting material in *Curcuma amada*, growth and yield of the plants are generally higher when compared to the plants produced from secondary fingers.

In the case of *Curcuma amada*, the present author could not trace much studies based on the relative performance of plants developed from seed rhizomes of different status. However, Rajagopalan and Gopalakrishnan (1985a) have reported in *Kaempferia galanga* that plants derived from mother rhizome showed significant superiority over other types of rhizome used as planting material.

Some studies on the effect of the size of seed rhizome on growth and yield have been made in turmeric by Randhawa and Mishra (1974) and Singh *et al*. (2000). They found that heavier rhizomes when used as planting materials showed higher yield. Hossain *et al*. (2005) observed that in *Curcuma longa*, seed rhizome should be 30-40 g with a large diameter and seed mother rhizome should be free from daughter rhizomes. Yothasiri *et al*. (1997) are of opinion that the primary, secondary and tertiary with 3-4 inter nodes did not differ from one another in terms of growth and yield. Maheswarappa *et al*. (1999b, 2000b, 2001) have also reported that in *Kaempferia galanga* when they used mother rhizome, they got higher yield.

4.1.7. Study of rhizome branching in *Curcuma amada* Roxb.

Curcuma amada is a perennial herb with an underground branched rhizome born horizontally and aerial shoot with leaves. The plant is propagated vegetatively and viable rhizome pieces are used as seed material. The rhizome has economic potential with medicinal and food values. The rhizomes have mango like aroma which is utilized in the preparation of value added products.

Table 4.13. Growth and yield characters of *Curcuma amada* Roxb. plants produced from planting materials of different status.

Sl. No.	Character	Mother rhizome			Primary fingers			Secondary fingers			CD (5%)
		Mean	Range	CV	Mean	Range	CV	Mean	Range	CV	
1	Days for germination	17.36	7 - 20	18.09	10.32	7 - 20	39.83	12.52	7 - 20	36.58	6.52
2	Plant height (cm)	90.07	61.5 - 122.0	15.47	85.29	55 - 150	23.65	83.49	36.50 - 122.50	26.73	NS
3	Number of tillers	1.18	1 - 2	33.05	1.16	1 - 2	31.90	1.28	1 - 2	35.16	NS
4	Number of leaves per tiller	6.98	5 - 10	14.33	6.78	5 - 11	18.58	7.06	4 - 11	20.11	NS
5	Leaf length (cm)	39.69	30.00 - 51.67	13.88	36.84	25.83 - 53.17	17.48	34.97	20.17 - 48.67	19.07	10.17
6	Leaf breadth (cm)	9.91	7.37 - 11.67	10.70	8.59	6.17 - 10.50	11.29	7.90	5.77 - 10.00	13.54	1.69
7	Leaf area (cm^2)	269.33	174.96 - 403.75	21.53	217.84	108.33 - 363.94	26.54	191.59	83.78 - 330.93	30.43	94.42
8	Number of primary fingers	3.66	1 - 5	23.77	3.28	1 - 6	29.57	3.30	1 - 5	29.39	NS
9	Number of secondary fingers	7.86	1 - 18	47.46	5.96	1 - 17	67.11	6.82	1 - 16	55.13	6.26
10	Length of primary fingers (cm)	9.50	6.00 - 11.83	14.84	8.45	3.00 - 13.50	28.52	8.66	2.83 - 12.50	27.95	3.49
11	Length of secondary fingers (cm)	6.58	1.20 - 10.67	26.60	5.50	1.20 - 10.83	41.45	5.88	1.50 - 10.17	37.24	3.41

12	Diameter of primary fingers (cm)	1.83	1.33 - 2.17	10.38	1.72	0.93 - 2.37	17.44	1.70	1.20 - 2.37	14.70	0.41
13	Diameter of secondary fingers (cm)	1.70	1.20 - 2.00	11.76	1.60	1.20 - 2.30	17.50	1.60	1.07 - 2.27	19.38	NS
14	Length of mother rhizome (cm)	4.77	3.00 - 9.00	25.37	4.49	3.00 - 6.50	20.94	4.35	2.50 - 8.50	27.36	NS
15	Diameter of mother rhizome (cm)	3.21	1.50 - 4.40	15.58	3.03	2.00 - 3.80	13.86	2.81	2.00 - 3.80	16.37	0.75
16	Yield per plant (g)	206.80	40 - 380	36.09	135.20	30 - 380	64.26	152.60	30 - 455	63.03	141.02

The branching pattern of rhizome in *Curcuma amada* has been studied presently by observing the nature of rhizomes in the case of 50 accessions studied for genetic variability. When healthy rhizome fingers were used as planting material, seed rhizomes germinated within 7-20 days after planting and formed the first tiller which produced leaves. The base of the tiller became swollen and developed into the mother rhizome (Figs. 4.12 and 4.13). From the mother rhizome primary branches developed towards different sides. The number of primary fingers ranged from three to six. The primaries produced secondaries and some of the secondary branches produced tertiary branches in turn.

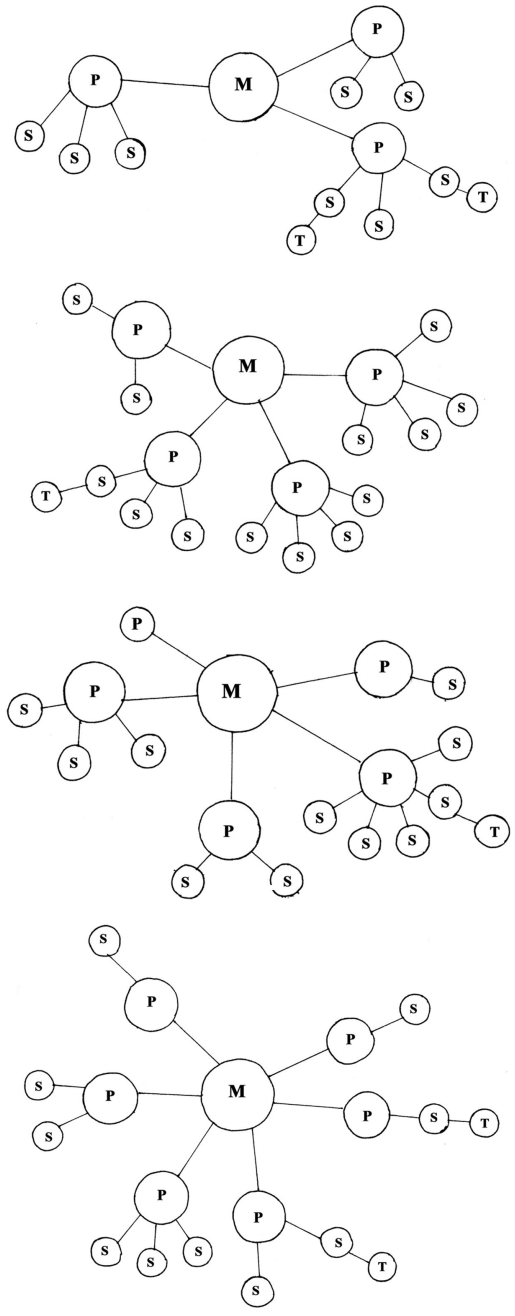
The primary branches showed positive geotropism in general. However some of them were negatively geotropic. A few of the primary branches produced tillers in some cases making the tiller number varying from 1-4.

Some earlier workers have also attempted to study rhizome branching in *Curcuma amada*. Shah and Raju (1975) studied rhizome branching in mango ginger and observed the same type of branching pattern. They observed that during early period of growth primary branches showed various geotropic responses. Jayachandran (1993) has reported the formation of second or third mother rhizome development depending upon vegetative growth of the plant.

Mohanan and Pavithran (2007) studied the chronology of tiller emergence in rice and revealed the emergence of primary, secondary and tertiary tillers following specific sequence intercepted by gap periods.

According to Ravindran *et al*. (2005) rhizome branching in ginger shows a sympodial pattern. The present study also shows that the pattern of rhizome branching in *Curcuma amada* is sympodial, but the development of primary fingers is limited to three to six in number.

Fig. 4.12. Rhizome branching in *Curcuma amada* Roxb. with 3, 4, 5 and 6 primary fingers respectively



M: Mother rhizome; P: Primary finger; S: Secondary finger; T: Tertiary finger

Fig 4.13. Rhizome branching in *Curcuma amada* Roxb.

4.2. *Kaempferia galanga* L.

4.2.1. Genetic variability

4.2.1.1. Frequency distribution of growth and yield characters

Frequency distribution analysis provides a basic idea of the genetic control of the characters under study and the nature of distribution of dominant and recessive alleles in the gene pool. 450 plants were grown for the purpose and observed for growth and yield characters at the age of 180 days (Table 4.14).

Plant height of *Kaempferia galanga* shows continuous and normal frequency distribution with more number of plants accumulated towards the second half of the frequency distribution. This type of distribution evidences the polygenic nature of the character and the distribution of higher number of dominant alleles in the gene pool. However, the number of plants with maximum plant height was lesser. Plant height of the species varied from 8 cm to 32.5 cm.

Number of leaves per plant varied from 3 to 59 in *Kaempferia galanga*. The frequency distribution was continuous showing polygenic control of the character but number of plants with higher number of leaves was comparatively lesser. This shows that the frequency of recessive alleles for the character is higher in the population and selection for the improvement of leaf number has good potential in the crop.

Leaf length of the plants varied from 5 to 22.5 cm, leaf breadth from 3 to 13 cm and leaf area from 12 to 159 cm^2. All the three characters showed continuous distribution with area of the frequency curve higher towards the second half of the distribution. This shows that frequency of plants with leaves larger than central value is higher.

The mother rhizome of the plant produces primary fingers and the primary finger produces secondary fingers towards all the sides of the rhizome. The number of primary fingers per plant varied from 0 to 6. Majority of the plants studied produced 2 to 4 primary fingers and the number of plants with higher and lower number of primary fingers was very low.

Number of secondary fingers ranged from 0 to 10 and the character showed continuous distribution. However, the number of plants with higher number of secondaries was lesser in the distribution. This shows that the frequency of recessive alleles is higher in the gene pool and the plants with higher number of secondary fingers can be selected.

The length of primary fingers varied from 0.5 to 4 cm and length of secondary fingers ranged from 0.8 to 3.6 cm. Both the characters showed continuous distribution thus evidencing their polygenic nature of control. However the frequency of plants with lesser length of primary and secondary fingers was higher when compared with the number of plants with length of primary and secondary fingers above the median value. This type of distribution shows higher frequency of recessive alleles in the gene pool of the character in the study population. This condition further indicates scope for selection of plants with optimum number of primary and secondary fingers.

Diameter of primary fingers and diameter of secondary fingers also show continuous frequency distribution indicating their polygenic control. However in both the cases, the number of plants with primary and secondary fingers with diameter below the median value is high. This shows the higher frequency of recessive alleles in their gene pool and the scope for selection.

Length of mother rhizome varied from 1 cm to 4 cm. Majority of the plants had a mother rhizome length between 1.6 cm and 2.8 cm. Frequency distribution analysis shows that frequency of plants with higher length of mother rhizome is lower in the population. This also shows higher frequency of recessive alleles in the gene pool of the character.

Diameter of mother rhizome varied from 1 cm to 3 cm. The character showed continuous frequency distribution. However the nature of skewness of the distribution shows accumulation of recessive alleles in the gene pool and the scope for selection.

Study of the frequency distribution of yield per plant in the case of *Kaempferia galanga* showed that it varied from 10 gm to 150 gm. The character shows continuous distribution but the graph is highly skewed towards the first half of the curve and the majority of the plants gives lower yield when compared to the high yielding plants. This observation necessitates selection for the character so as to eliminate the low yielding genotypes from the agronomic seed stocks and also selection for higher yield per plant (Table 4.14).

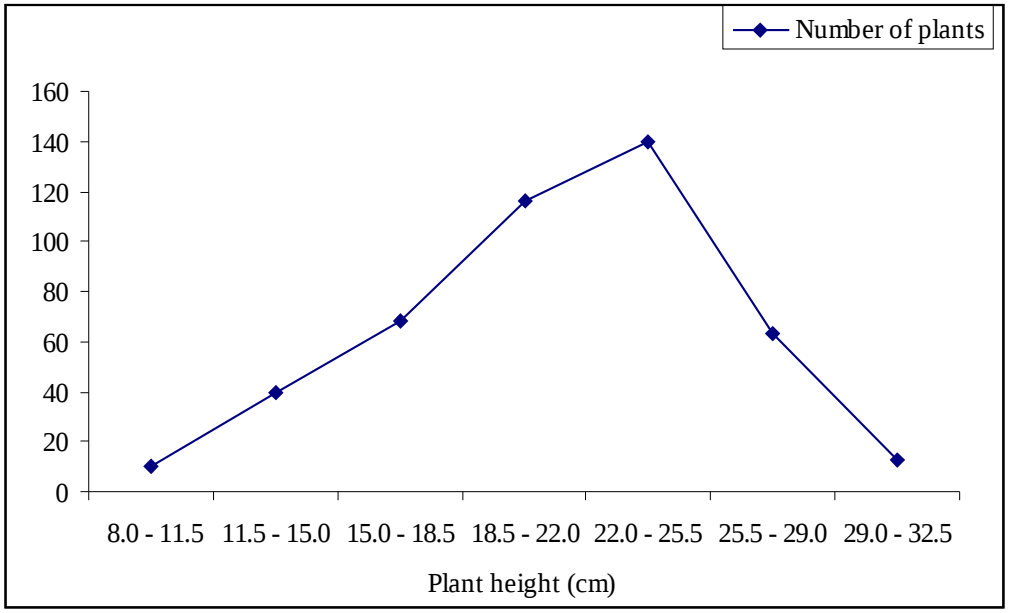
The above study shows that all the agronomic characters of *Kaempferia galanga* analyzed presently show continuous distribution and polygenic genetic control. In the case of growth characters like plant height, leaf length, leaf breadth and leaf area, the number of plants with higher values is more when compared to the plants with lower values. In the case of number of leaves, number of secondary fingers, length of primary fingers, length of secondary fingers, diameter of primary fingers, diameter of secondary fingers, length of mother rhizome and diameter of mother rhizome, more number of plants showed values below the central value. Only a few plants showed high yield whereas majority of them showed yield levels below the central value. Selection of desirable

genotypes with optimum expression of growth and other agronomic characters and maximum yield can be adopted to improve the agronomic status of planting materials being made available to the farmers. However the entire diversity is to be conserved as such because *Kaempferia galanga* has been facing considerable levels of threat from damages of ecosystems, developmental activities and abandoning of conventional farming practices that have been necessitated by the new technologies and policies in the agriculture sector. Being a plant species with very high medicinal potential, the plant is to be conserved, improved and propagated more effectively.

Frequency distribution analysis to study the nature of distribution of alleles of agronomic characters in the gene pool of crops and medicinal plants have been carried out by different workers like Dharmaraj and Sreenivasan (1992); Raghu *et al*. (2003) and Nikhila (2007) in coffee; Paramasivan and Sreerangasamy (1988) in cereals; Jayasree (2002) in butterfly pea; Chandramohanan and Mohanan (2005) in *Cassia tora* and Umamaheswari and Mohanan (2004) in vanilla.

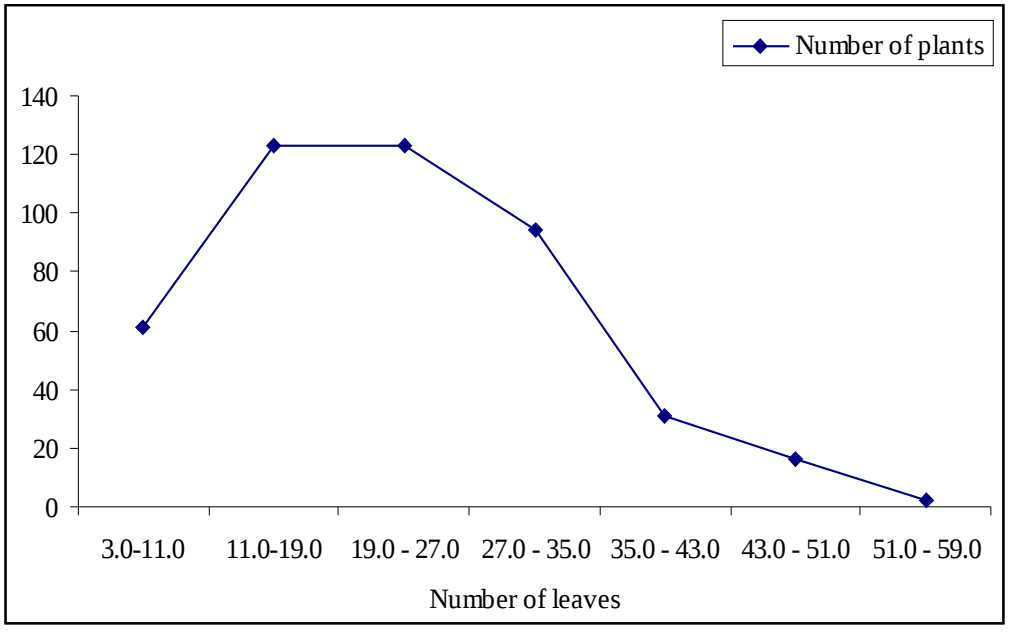
Table 4.14. Frequency distribution of growth and yield characters of *Kaempferia galanga* L.

Character / Distribution	Number of plants
1. Plant height (cm)	
8.0 - 11.5	10
11.5 - 15.0	40
15.0 - 18.5	68
18.5 - 22.0	116
22.0 - 25.5	140
25.5 - 29.0	63
29.0 - 32.5	13

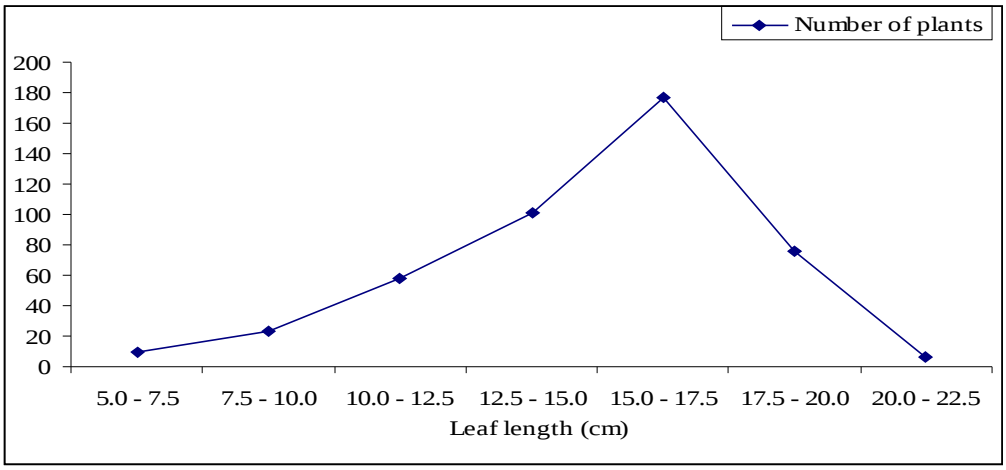


2. Number of leaves

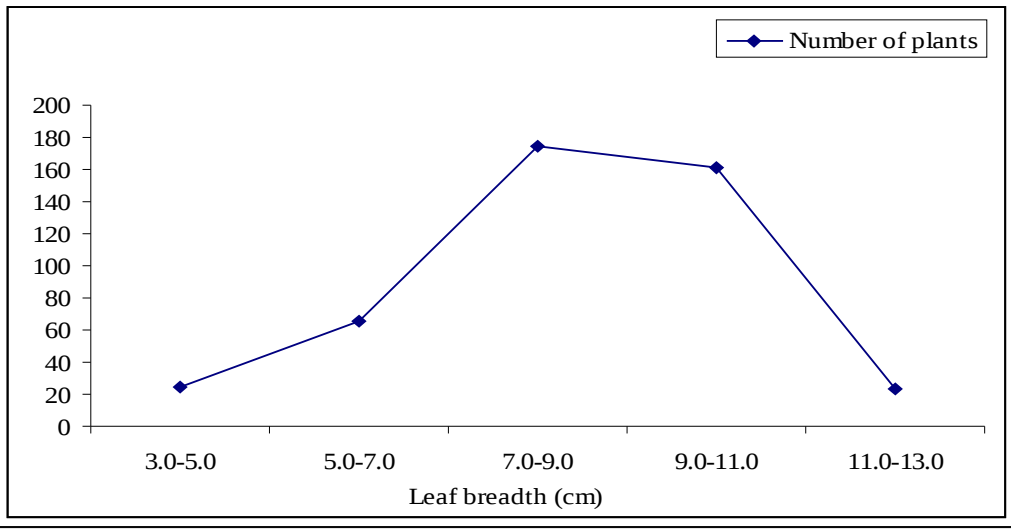
3 - 11	61
11 - 19	123
19 - 27	123
27 - 35	94
35 - 43	31
43 - 51	16
51 - 59	2



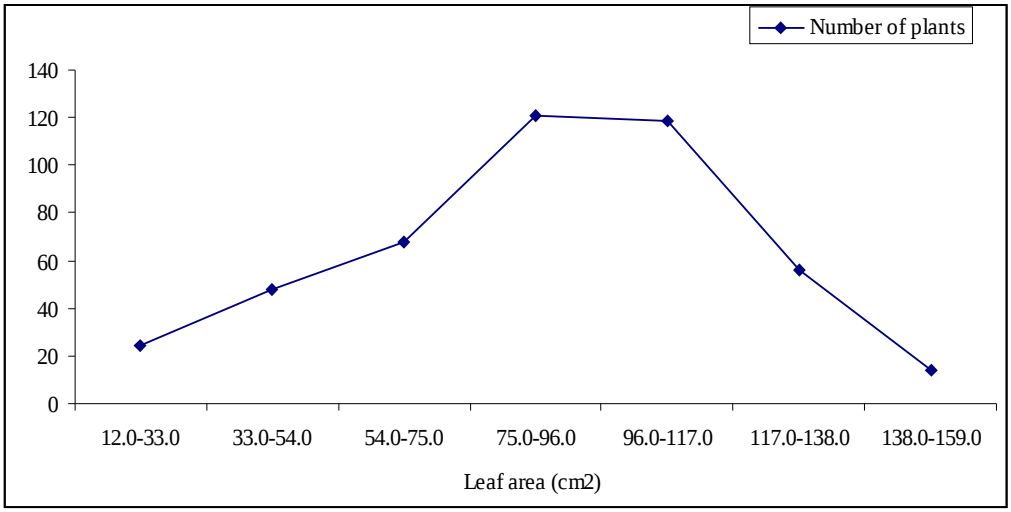
3. Leaf length (cm)	
5.0 - 7.5	9
7.5 - 10.0	23
10.0 - 12.5	58
12.5 - 15.0	101
15.0 - 17.5	177
17.5 - 20.0	76
20.0 - 22.5	6



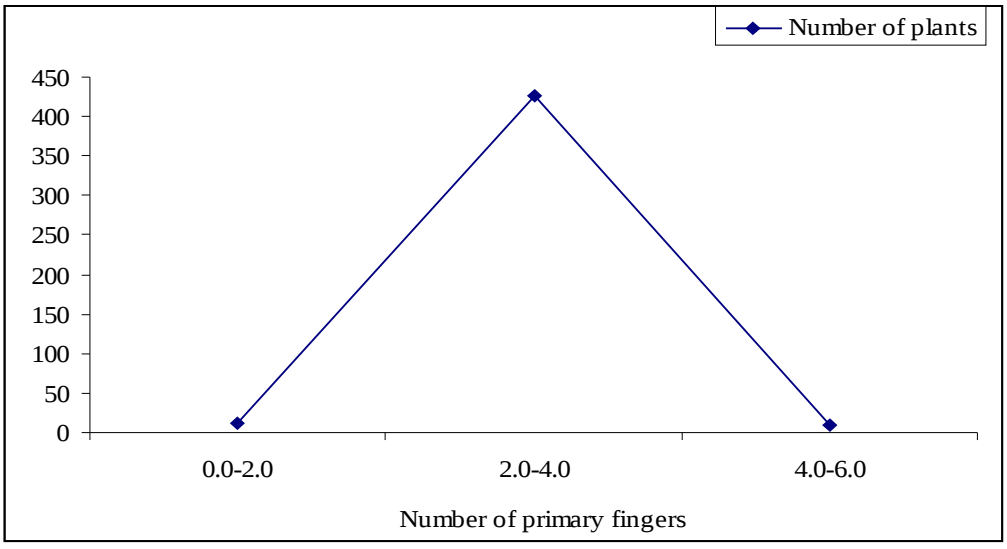
4. Leaf breadth (cm)	
3 - 5	25
5 - 7	66
7 - 9	175
9 - 11	161
11 - 13	23



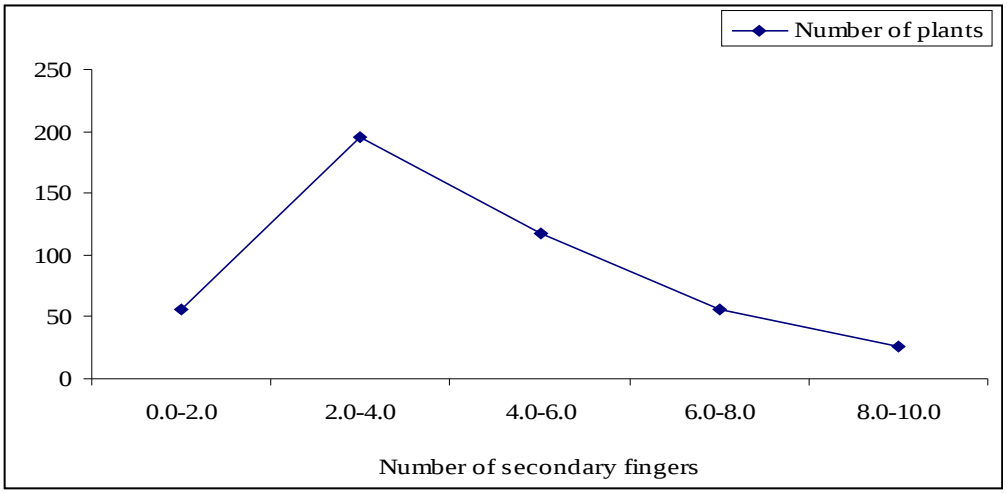
5. Leaf area (cm^2)	
12 - 33	24
33 - 54	48
54 - 75	68
75 - 96	121
96 - 117	119
117 - 138	56
138 - 159	14



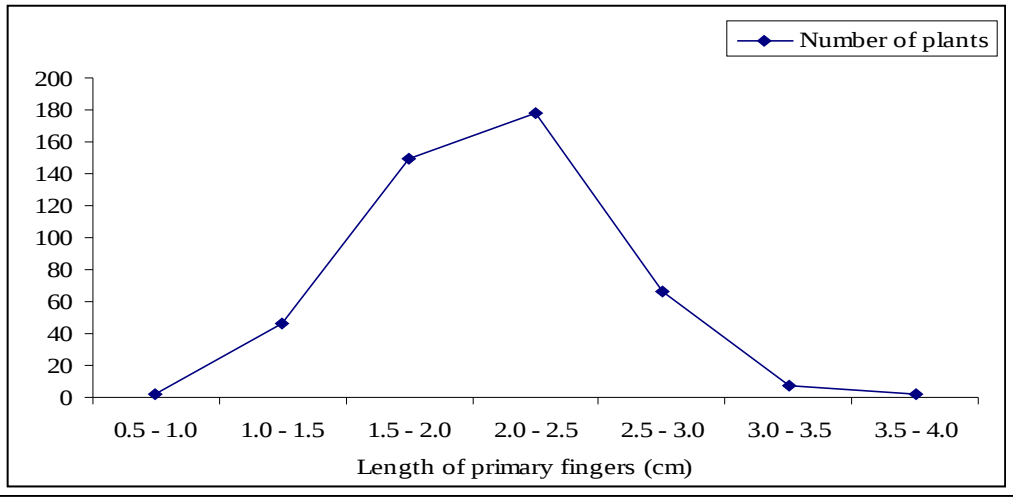
6. Number of primary fingers	
0-2	13
2-4	427
4-6	10



7. Number of secondary fingers	
0 - 2	56
2 - 4	195
4 - 6	117
6 - 8	56
8 - 10	26

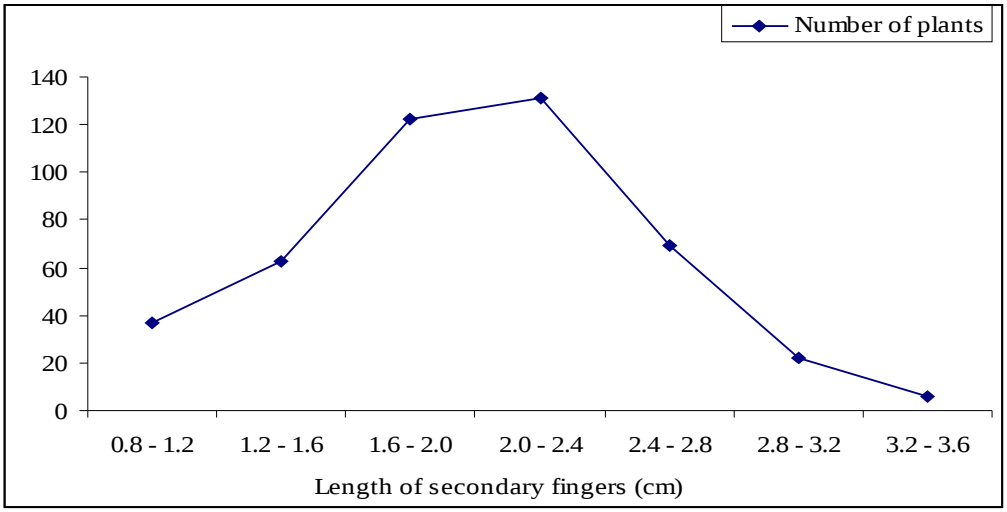


8. Length of primary fingers (cm)	
0.5 - 1.0	2
1.0 - 1.5	46
1.5 - 2.0	149
2.0 - 2.5	178
2.5 - 3.0	66
3.0 - 3.5	7
3.5 - 4.0	2



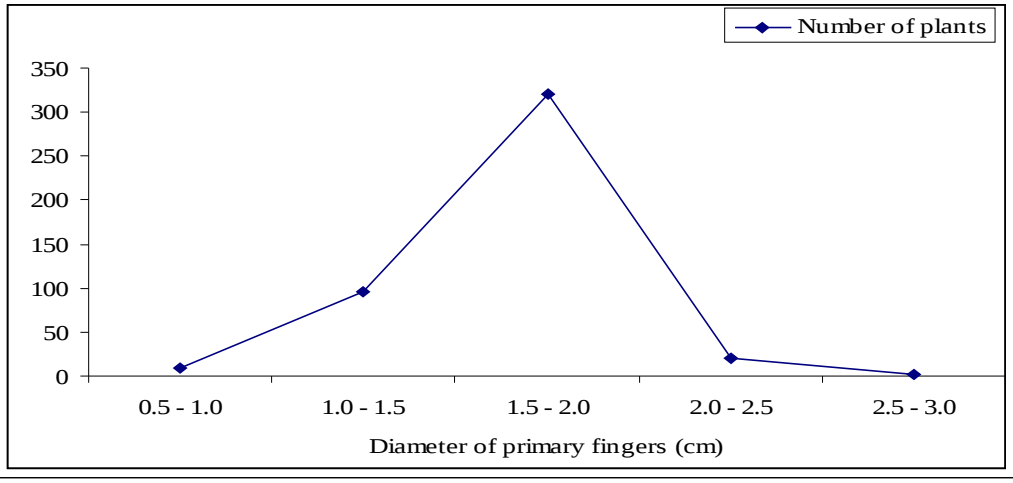
9. Length of secondary fingers (cm)

0.8 - 1.2	37
1.2 - 1.6	63
1.6 - 2.0	122
2.0 - 2.4	131
2.4 - 2.8	69
2.8 - 3.2	22
3.2 - 3.6	6

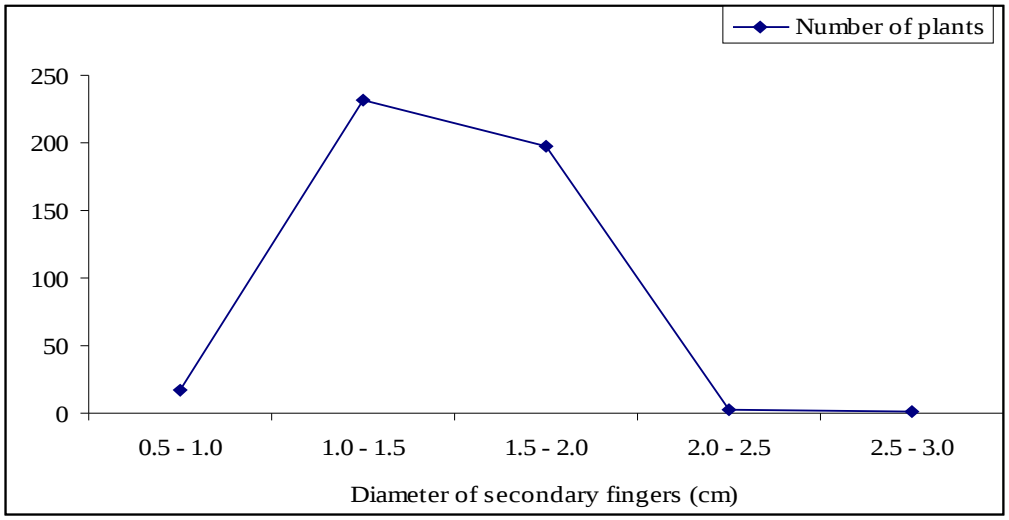


10. Diameter of primary fingers (cm)

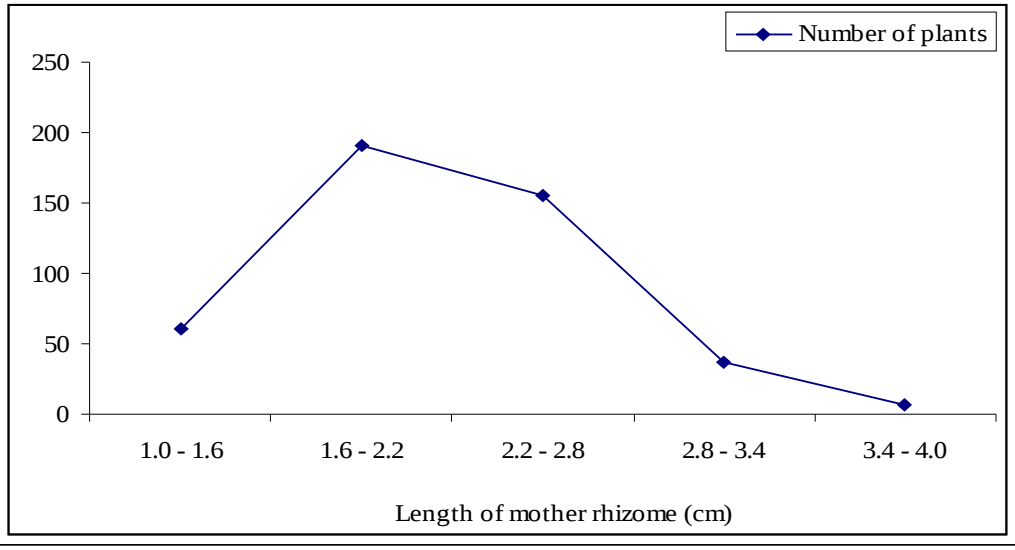
0.5 - 1.0	10
1.0 - 1.5	96
1.5 - 2.0	321
2.0 - 2.5	21
2.5 - 3.0	2



11. Diameter of secondary fingers (cm)	
0.5 - 1.0	17
1.0 - 1.5	232
1.5 - 2.0	198
2.0 - 2.5	2
2.5 - 3.0	1

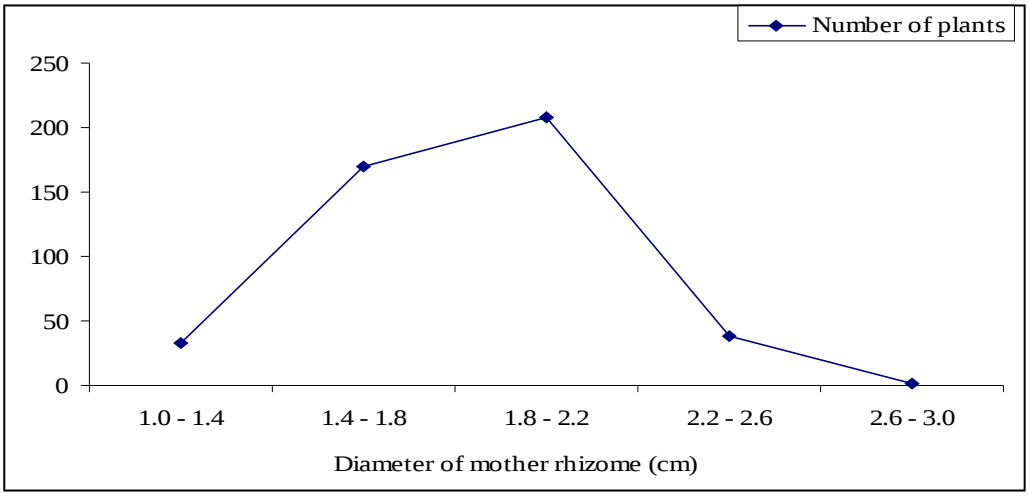


12. Length of mother rhizome (cm)	
1.0 - 1.6	60
1.6 - 2.2	191
2.2 - 2.8	155
2.8 - 3.4	37
3.4 - 4.0	7



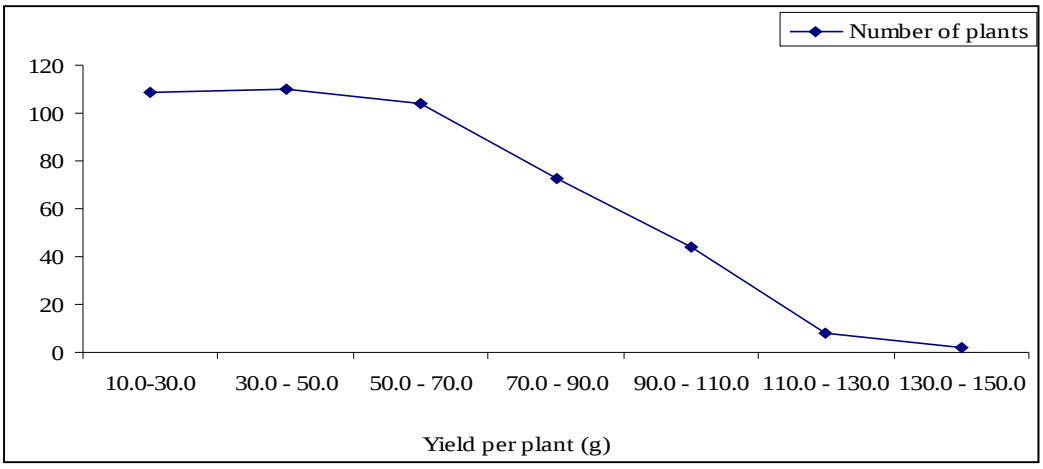
13. Diameter of mother rhizome (cm)

1.0 - 1.4	33
1.4 - 1.8	170
1.8 - 2.2	208
2.2 - 2.6	38
2.6 - 3.0	1



14. Yield per plant (g)

10 - 30	109
30 - 50	110
50 - 70	104
70 - 90	73
90 - 110	44
110 - 130	8
130 - 150	2



4.2.1.2. Phenotypic and genotypic variability

Kaempferia galanga L. is a crop being cultivated in the homesteads of Kerala state for centuries on a marginal scale. However recent advances in the strategies and technologies of agriculture have resulted in further marginalization of the crop making it rare in the homesteads. Even though some crop improvement activities have been carried out in the species (Anonymous, 2003a) concerted efforts to pool up the germplasm and also to study its variability have not been carried out in the species on a considerable scale. Hence it is necessary that a genetic stock taking of the crop is made and potential genotypes identified. A study has been designed presently to assess the genotypic variability of the species based on 50 accessions of the species as described elsewhere. The major findings of the study are presented and discussed below.

4.2.1.2.1. Variability of agronomic characters

Phenotypic and genotypic variability of characters in *Kaempferia galanga* L. has been assessed presently based on five growth characters and nine yield characters (Tables 4.15 and 4.16). All the five growth characters studied presently showed statistically significant variations. Mean plant height was found to be 20.98 cm, mean number of leaves 21.7, mean leaf length 14.89 cm, mean leaf breadth 8.34 cm and mean leaf area 87.09 cm^2. Among the growth characters the highest coefficient of variation was shown by number of leaves (33.55%) followed by leaf area (26.32%). Plant height showed a coefficient of variation of 16.78%, leaf length showed 15.04% and leaf breadth showed a coefficient of variation of 15.59%.

Mean number of primary fingers was 2.47, number of secondary fingers 3.59, length of primary fingers 2.22 cm, length of secondary fingers 2.19 cm, diameter of primary fingers 1.77 cm, diameter of secondary fingers 1.57 cm, length of mother rhizome 2.10 cm, diameter of mother rhizome 1.75 cm and yield

per plant 51.31 g. Among the nine yield characters seven showed statistically significant variation between accessions. Number of primary fingers, number of secondary fingers, length of mother rhizome, diameter of mother rhizome and yield per plant showed statistically significant variation at 1% level and length of primary fingers and length of secondary fingers showed statistically significant variation at 5% level. Diameter of primary fingers and secondary fingers did not show statistically significant variation (Table 4.16).

Among the yield characters, the highest coefficient of variation was shown by yield per plant (42.56%) followed by number of secondary fingers (39.83%). The lowest coefficient of variation was shown by diameter of mother rhizome (10.86%). In the case of all the characters that showed statistically significant variation, phenotypic coefficient of variation was higher than genotypic coefficient of variation. This indicates additive polygenic nature of characters (Table 4.17). Among the growth characters, the highest phenotypic coefficient of variation (PCV) was shown by number of leaves (36.68%) followed by leaf area (28.12%). This shows that number of leaves is the most variable vegetative character in *Kaempferia galanga* followed by leaf area. Genotypic coefficient of variation (GCV) also showed the same trend of variation in the case of the growth characters of *Kaempferia galanga*.

Among the yield characters, the highest PCV (44.94%) was shown by yield per plant followed by number of secondary fingers (43.73%) and lowest PCV (12.57%) was shown by diameter of mother rhizome. GCV also showed the same trend (Table 4.17).

Analysis of phenotypic and genotypic coefficients of variation has been attempted in different crop plants like soybean (Nirmalakumari and Balasubramanian, 1993), turmeric (Narayanpur and Hanamashetti, 2003),

coriander (Tripathi *et al*., 2000) betel vine (Reddy, 1994), cardamom (Radhakrishnan *et al*., 2006a), coffee (Nikhila, 2007), tea (Ramasubramanian, 2005) and vanilla (Umamaheswari, 2008).

High difference between PCV and GCV indicates influence of environment on the characters under study and small difference indicates lesser influence of the environment on the characters.

Table 4.15. Genetic variability of the morphological characters of *Kaempferia galanga* L. studied (vegetative characters)

Acc. No.	Plant height (cm) **	Number of leaves **	Leaf length (cm) **	Leaf breadth (cm) **	Leaf area (cm^2) **
CUK 1	21.70 ± 1.56	31.80 ± 3.56	16.30 ± 1.31	9.93 ± 0.93	111.53 ± 16.03
CUK 2	17.20 ± 1.23	19.56 ± 6.17	14.07 ± 1.27	8.93 ± 0.72	85.43 ± 13.50
CUK 3	19.37 ± 0.22	25.87 ± 3.50	15.17 ± 0.74	8.53 ± 0.15	88.47 ± 3.10
CUK 4	17.97 ± 1.79	20.97 ± 7.09	13.73 ± 1.00	8.47 ± 0.38	81.00 ± 4.33
CUK 5	18.33 ± 0.47	25.77 ± 2.15	13.03 ± 0.42	7.97 ± 0.55	72.47 ± 7.70
CUK 6	17.10 ± 0.70	28.33 ± 3.88	13.13 ± 0.90	7.77 ± 0.76	73.17 ± 11.91
CUK 7	21.10 ± 1.08	28.33 ± 3.51	14.20 ± 1.41	8.90 ± 0.69	85.20 ± 5.52
CUK 8	22.07 ± 0.90	31.13 ± 5.69	15.33 ± 0.47	8.03 ± 0.55	83.83 ± 7.74
CUK 9	20.57 ± 1.45	32.00 ± 5.47	15.27 ± 0.15	8.60 ± 0.75	89.47 ± 8.66
CUK 10	22.33 ± 0.40	35.30 ± 4.00	16.23 ± 0.15	8.73 ± 0.90	96.87 ± 10.30
CUK 11	22.57 ± 1.60	29.33 ± 2.35	15.90 ± 0.53	8.93 ± 1.01	97.43 ± 14.00
CUK 12	23.97 ± 1.39	38.77 ± 5.22	16.10 ± 0.62	8.70 ± 0.70	95.77 ± 11.64
CUK 13	24.00 ± 0.20	35.23 ± 2.25	16.87 ± 0.32	9.27 ± 0.38	106.87 ± 5.12
CUK 14	24.60 ± 0.52	25.57 ± 3.09	17.23 ± 0.72	10.07 ± 0.50	117.53 ± 2.17

CUK 15	20.60 ± 1.77	17.77 ± 5.97	16.03 ± 1.22	10.03 ± 0.38	111.57 ± 9.35
CUK 16	23.37 ± 0.80	25.90 ± 6.41	17.07 ± 1.19	9.60 ± 0.95	112.27 ± 17.93
CUK 17	21.37 ± 1.68	20.20 ± 5.28	15.30 ± 0.26	10.07 ± 0.40	104.97 ± 2.95
CUK 18	22.43 ± 1.77	21.47 ± 1.96	16.13 ± 1.10	9.47 ± 0.23	103.80 ± 8.75
CUK 19	19.60 ± 0.80	18.23 ± 2.04	14.80 ± 2.50	8.57 ± 0.59	89.77 ± 16.01
CUK 20	22.20 ± 3.14	18.57 ± 0.22	15.20 ± 1.25	8.37 ± 0.87	87.70 ± 15.19
CUK 21	24.47 ± 1.21	25.77 ± 5.22	16.87 ± 1.36	9.70 ± 0.78	111.90 ± 14.84
CUK 22	21.30 ± 0.62	25.10 ± 3.77	15.03 ± 0.51	9.37 ± 0.90	97.03 ± 11.85
CUK 23	21.43 ± 1.20	20.53 ± 2.36	15.37 ± 0.84	9.27 ± 0.80	97.00 ± 10.45
CUK 24	21.90 ± 1.65	17.00 ± 3.30	16.47 ± 1.22	9.60 ± 0.52	107.90 ± 11.08
CUK 25	19.90 ± 1.35	16.10 ± 1.71	14.33 ± 1.75	8.10 ± 0.44	81.70 ± 13.42
CUK 26	23.83 ± 3.80	24.53 ± 3.28	16.43 ± 1.59	9.73 ± 0.50	109.67 ± 15.91
CUK 27	19.20 ± 2.35	19.10 ± 9.73	14.16 ± 0.23	9.03 ± 0.40	87.33 ± 4.64
CUK 28	25.80 ± 0.89	16.00 ± 2.86	17.50 ± 1.06	9.63 ± 0.45	115.07 ± 7.66
CUK 29	24.13 ± 0.76	24.67 ± 2.08	16.83 ± 1.33	8.93 ± 0.65	102.27 ± 12.41
CUK 30	23.10 ± 0.17	14.10 ± 0.85	16.63 ± 0.86	8.93 ± 0.81	101.47 ± 9.10
CUK 31	26.53 ± 1.77	22.87 ± 4.07	17.10 ± 0.53	9.60 ± 0.66	112.13 ± 5.48
CUK 32	17.43 ± 1.27	20.33 ± 2.71	12.23 ± 0.71	6.50 ± 0.72	54.77 ± 8.88
CUK 33	25.87 ± 0.72	23.63 ± 3.51	17.07 ± 0.30	8.73 ± 0.45	101.57 ± 5.78
CUK 34	25.77 ± 1.22	20.63 ± 3.05	18.13 ± 0.51	9.87 ± 1.16	122.57 ± 17.01
CUK 35	27.37 ± 1.51	31.46 ± 3.33	17.77 ± 0.64	7.77 ± 0.50	94.70 ± 8.64
CUK 36	25.10 ± 1.45	24.10 ± 4.46	17.83 ± 0.76	8.87 ± 0.21	108.93 ± 3.36
CUK 37	23.47 ± 3.56	22.67 ± 3.15	16.33 ± 1.60	8.10 ± 0.62	92.07 ± 12.86

CUK 38	24.80 ± 2.29	24.77 ± 5.17	16.83 ± 0.11	8.20 ± 0.35	94.90 ± 4.84
CUK 39	25.13 ± 1.36	27.23 ± 5.00	17.10 ± 0.70	7.77 ± 0.30	90.53 ± 6.94
CUK 40	18.37 ± 2.44	13.10 ± 2.03	13.33 ± 1.40	8.27 ± 0.42	74.77 ± 9.65
CUK 41	17.60 ± 1.08	9.67 ± 2.31	12.97 ± 0.21	7.30 ± 0.75	65.30 ± 7.42
CUK 42	18.00 ± 2.95	15.10 ± 4.33	12.53 ± 2.70	6.47 ± 1.26	57.27 ± 23.15
CUK 43	18.37 ± 2.95	13.80 ± 2.48	13.30 ± 0.95	6.97 ± 0.64	63.70 ± 9.35
CUK 44	14.77 ± 0.24	10.80 ± 1.56	10.70 ± 0.26	5.53 ± 0.05	41.00 ± 1.37
CUK 45	15.73 ± 2.11	12.00 ± 2.93	11.07 ± 0.38	5.73 ± 0.85	46.13 ± 8.75
CUK 46	15.33 ± 1.34	14.57 ± 3.58	10.97 ± 0.67	6.20 ± 0.95	46.87 ± 9.52
CUK 47	14.57 ± 0.55	10.00 ± 1.17	10.47 ± 0.60	6.30 ± 0.35	46.57 ± 6.70
CUK 48	14.17 ± 1.60	7.20 ± 0.85	9.90 ± 0.10	6.13 ± 0.40	41.70 ± 2.65
CUK 49	16.10 ± 1.99	17.33 ± 1.65	11.00 ± 1.70	5.40 ± 0.85	43.00 ± 14.00
CUK 50	16.87 ± 1.20	12.77 ± 3.36	11.33 ± 0.78	6.30 ± 0.20	50.23 ± 3.19
Mean	20.98	21.70	14.89	8.34	87.09
Range	8.4 - 31.2	3 - 53	5.7 - 21.7	3.3 - 12.7	12.8 - 153
SD	3.52	7.28	2.24	1.30	22.92
CV	16.78	33.55	15.04	15.59	26.32
CD @ 5%	2.69	6.44	1.72	1.08	17.21

**: significant at 1% level

Table 4.16. Genetic variability of the morphological characters of *Kaempferia galanga* L. studied (yield characters)

Acc. No.	Number of primary fingers **	Number of secondary fingers **	Length of primary fingers (cm) *	Length of secondary fingers (cm) *	Diameter of primary fingers (cm) NS	Diameter of secondary fingers (cm) NS	Length of mother rhizome (cm) **	Diameter of mother rhizome (cm) **	Yield per plant (g) **
CUK 1	3.10 ± 0.17	6.67 ± 0.35	1.90 ± 0.10	2.27 ± 0.29	1.70 ± 0.17	1.60 ± 0.17	2.17 ± 0.05	1.93 ± 0.15	88.87 ± 5.10
CUK 2	3.20 ± 0.17	5.10 ± 0.35	2.50 ± 0.78	2.40 ± 0.56	2.03 ± 0.40	1.83 ± 0.51	2.07 ± 0.05	2.07 ± 0.15	88.33 ± 7.30
CUK 3	3.10 ± 0.17	6.10 ± 0.17	2.07 ± 0.21	2.00 ± 0.30	1.77 ± 0.15	1.60 ± 0.10	2.20 ± 0.53	1.90 ± 0.10	86.10 ± 5.35
CUK 4	2.57 ± 0.51	6.00 ± 0.89	2.40 ± 0.50	2.60 ± 0.62	2.30 ± 0.61	2.03 ± 0.57	1.93 ± 0.05	2.13 ± 0.21	90.57 ± 15.16
CUK 5	2.43 ± 0.23	2.80 ± 0.85	2.03 ± 0.05	1.87 ± 0.05	1.73 ± 0.05	1.67 ± 0.05	2.20 ± 0.20	1.80 ± 0.10	71.10 ± 16.80
CUK 6	2.67 ± 0.35	4.20 ± 0.17	2.57 ± 0.90	2.10 ± 0.30	2.00 ± 0.66	1.87 ± 0.40	2.13 ± 0.15	1.83 ± 0.15	73.87 ± 4.18
CUK 7	2.80 ± 0.17	3.80 ± 0.85	2.27 ± 0.11	2.20 ± 0.10	1.73 ± 0.05	1.57 ± 0.05	2.10 ± 0.00	1.80 ± 0.10	76.67 ± 13.61
CUK 8	3.10 ± 0.17	5.10 ± 1.01	2.60 ± 0.96	2.60 ± 0.69	2.07 ± 0.72	1.93 ± 0.67	2.07 ± 0.15	1.97 ± 0.11	79.43 ± 16.73
CUK 9	2.70 ± 0.00	3.67 ± 0.35	1.97 ± 0.05	1.83 ± 0.21	1.57 ± 0.05	1.40 ± 0.10	1.93 ± 0.15	1.80 ± 0.17	67.77 ± 12.32
CUK 10	2.80 ± 0.17	5.23 ± 1.08	2.70 ± 1.04	2.90 ± 0.95	2.00 ± 0.53	1.80 ± 0.55	2.30 ± 0.20	1.97 ± 0.21	76.10 ± 11.85

CUK 11	2.70 ± 0.00	4.23 ± 1.29	2.23 ± 0.05	2.10 ± 0.10	1.70 ± 0.17	1.53 ± 0.05	2.30 ± 0.20	1.97 ± 0.15	77.23 ± 10.72
CUK 12	2.67 ± 0.35	6.33 ± 0.91	2.83 ± 0.84	2.93 ± 0.92	2.00 ± 0.61	1.90 ± 0.70	2.30 ± 0.10	1.83 ± 0.15	80.57 ± 12.27
CUK 13	3.10 ± 0.17	5.23 ± 0.68	2.13 ± 0.05	2.30 ± 0.10	1.63 ± 0.05	1.57 ± 0.05	2.30 ± 0.35	1.73 ± 0.15	65.00 ± 4.40
CUK 14	2.67 ± 0.35	5.23 ± 0.68	2.63 ± 0.75	2.97 ± 1.50	2.07 ± 0.64	1.90 ± 0.61	2.23 ± 0.05	1.97 ± 0.05	53.87 ± 10.05
CUK 15	2.80 ± 0.17	4.23 ± 1.36	2.13 ± 0.21	2.20 ± 0.36	1.63 ± 0.15	1.47 ± 0.15	2.30 ± 0.20	2.03 ± 0.15	61.67 ± 1.65
CUK 16	2.90 ± 0.17	5.57 ± 1.50	2.53 ± 0.76	2.70 ± 0.79	2.00 ± 0.52	2.03 ± 0.75	2.03 ± 0.25	1.73 ± 0.25	55.00 ± 5.00
CUK 17	2.57 ± 0.23	3.77 ± 0.50	2.23 ± 0.21	2.50 ± 0.36	1.70 ± 0.17	1.43 ± 0.11	2.50 ± 0.17	1.90 ± 0.00	71.10 ± 6.75
CUK 18	2.90 ± 0.17	4.13 ± 0.51	2.63 ± 0.84	2.53 ± 0.40	2.13 ± 0.57	1.93 ± 0.59	1.87 ± 0.21	1.97 ± 0.21	63.90 ± 15.51
CUK 19	2.43 ± 0.23	3.47 ± 0.68	2.13 ± 0.21	2.23 ± 0.11	1.57 ± 0.23	1.47 ± 0.23	2.20 ± 0.17	1.83 ± 0.11	55.00 ± 14.23
CUK 20	2.33 ± 0.35	3.23 ± 0.68	2.87 ± 0.81	2.53 ± 0.21	2.00 ± 0.70	1.70 ± 0.35	2.50 ± 0.20	1.83 ± 0.29	50.53 ± 6.93
CUK 21	2.57 ± 0.23	4.77 ± 2.20	2.27 ± 0.42	2.10 ± 0.30	1.70 ± 0.10	1.47 ± 0.15	2.33 ± 0.21	1.77 ± 0.11	56.10 ± 9.75
CUK 22	2.90 ± 0.17	4.00 ± 1.00	2.30 ± 0.72	2.23 ± 0.97	2.00 ± 0.53	1.40 ± 0.50	2.17 ± 0.15	1.80 ± 0.10	51.13 ± 4.18
CUK 23	2.80 ± 0.17	5.00 ± 0.70	2.10 ± 0.10	2.00 ± 0.20	1.57 ± 0.05	1.43 ± 0.05	2.07 ± 0.15	1.73 ± 0.05	59.47 ± 8.57
CUK 24	2.43 ± 0.23	3.80 ± 0.17	2.73 ± 1.27	3.00 ± 1.48	2.30 ± 0.04	1.80 ± 0.62	2.17 ± 0.15	1.93 ± 0.15	53.33 ± 6.01
CUK 25	2.33 ± 0.57	2.00 ± 0.30	2.00 ± 0.20	2.00 ± 0.26	1.57 ± 0.05	1.40 ± 0.10	2.13 ± 0.25	1.67 ± 0.11	45.57 ± 14.16

CUK 26	2.43 ± 0.23	3.10 ± 0.72	2.83 ± 0.84	2.90 ± 0.79	2.13 ± 0.75	1.87 ± 0.63	2.43 ± 0.35	1.87 ± 0.11	63.90 ± 18.01
CUK 27	2.43 ± 0.23	2.10 ± 0.72	1.73 ± 0.21	1.67 ± 0.21	1.73 ± 0.05	1.50 ± 0.10	1.87 ± 0.25	1.87 ± 0.11	46.10 ± 3.81
CUK 28	2.20 ± 0.17	2.77 ± 0.68	2.40 ± 0.46	2.40 ± 0.70	2.13 ± 0.67	1.97 ± 0.55	2.07 ± 0.42	1.90 ± 0.10	52.20 ± 10.18
CUK 29	2.43 ± 0.23	3.57 ± 0.51	2.17 ± 0.23	1.97 ± 0.15	1.73 ± 0.05	1.53 ± 0.05	2.10 ± 0.10	1.87 ± 0.05	55.00 ± 4.40
CUK 30	2.33 ± 0.35	2.23 ± 0.68	2.73 ± 0.15	3.30 ± 1.65	2.03 ± 0.76	1.67 ± 0.74	2.87 ± 0.32	1.70 ± 0.20	38.90 ± 7.52
CUK 31	2.20 ± 0.17	3.90 ± 1.01	2.77 ± 0.05	2.60 ± 0.26	1.73 ± 0.21	1.60 ± 0.10	2.57 ± 0.42	1.80 ± 0.17	60.00 ± 19.25
CUK 32	2.23 ± 0.50	1.43 ± 0.23	1.70 ± 0.17	1.83 ± 0.71	1.50 ± 0.26	1.40 ± 0.35	1.83 ± 0.15	1.43 ± 0.05	24.43 ± 1.96
CUK 33	2.53 ± 0.40	2.33 ± 0.35	2.10 ± 0.10	1.73 ± 0.15	1.60 ± 0.00	1.33 ± 0.05	2.17 ± 0.25	1.67 ± 0.05	40.57 ± 5.10
CUK 34	2.33 ± 0.35	2.77 ± 0.68	2.63 ± 0.49	2.43 ± 0.49	2.07 ± 0.90	1.77 ± 0.63	2.17 ± 0.15	1.67 ± 0.15	46.10 ± 7.88
CUK 35	2.23 ± 0.40	3.80 ± 0.85	2.20 ± 0.26	2.17 ± 0.38	1.67 ± 0.05	1.47 ± 0.05	2.17 ± 0.25	1.60 ± 0.00	41.10 ± 6.97
CUK 36	2.33 ± 0.57	4.47 ± 1.36	2.47 ± 0.55	2.37 ± 0.99	2.00 ± 0.79	1.60 ± 0.61	2.03 ± 0.25	1.70 ± 0.17	45.00 ± 1.70
CUK 37	2.00 ± 0.00	3.00 ± 0.30	2.13 ± 0.15	2.00 ± 0.10	1.50 ± 0.17	1.33 ± 0.11	2.10 ± 0.10	1.60 ± 0.17	40.00 ± 8.66
CUK 38	2.67 ± 0.35	4.87 ± 0.75	2.27 ± 0.47	2.50 ± 0.70	1.93 ± 0.75	1.67 ± 0.38	2.27 ± 0.47	1.67 ± 0.05	41.67 ± 1.65
CUK 39	2.90 ± 0.17	3.77 ± 0.50	1.77 ± 0.21	2.13 ± 0.13	1.43 ± 0.05	1.43 ± 0.05	1.90 ± 0.17	1.63 ± 0.11	42.23 ± 7.51
CUK 40	2.33 ± 0.57	2.67 ± 1.15	2.10 ± 0.20	1.97 ± 0.25	1.93 ± 0.51	1.63 ± 0.59	1.97 ± 0.11	1.73 ± 0.05	29.43 ± 4.18

CUK 41	1.76 ± 0.40	2.23 ± 0.50	1.93 ± 0.45	1.47 ± 0.21	1.33 ± 0.15	1.13 ± 0.21	2.03 ± 0.25	1.57 ± 0.15	17.20 ± 5.35
CUK 42	2.10 ± 0.17	2.10 ± 0.17	1.70 ± 0.30	1.47 ± 0.21	1.57 ± 0.57	1.33 ± 0.40	1.90 ± 0.10	1.40 ± 0.17	20.57 ± 4.18
CUK 43	1.90 ± 0.17	2.00 ± 0.89	1.47 ± 0.11	1.53 ± 0.15	1.27 ± 0.15	1.13 ± 0.21	1.80 ± 0.35	1.40 ± 0.10	20.00 ± 7.24
CUK 44	1.67 ± 0.65	1.43 ± 0.51	1.97 ± 0.23	1.93 ± 0.51	1.57 ± 0.57	1.30 ± 0.36	2.00 ± 0.44	1.37 ± 0.15	19.46 ± 2.54
CUK 45	1.80 ± 0.17	1.80 ± 0.17	1.67 ± 0.64	1.60 ± 0.36	1.23 ± 0.21	1.20 ± 0.10	1.73 ± 0.40	1.43 ± 0.15	19.43 ± 3.44
CUK 46	2.20 ± 0.17	1.90 ± 0.17	2.13 ± 0.55	2.03 ± 0.84	1.63 ± 0.49	1.40 ± 0.20	1.97 ± 0.21	1.40 ± 0.00	21.70 ± 1.07
CUK 47	2.00 ± 0.00	1.30 ± 0.00	1.43 ± 0.23	1.53 ± 0.25	1.33 ± 0.05	1.13 ± 0.05	1.40 ± 0.10	1.47 ± 0.05	16.67 ± 1.65
CUK 48	2.00 ± 0.30	1.23 ± 0.40	2.03 ± 0.70	1.87 ± 1.07	1.70 ± 0.72	1.53 ± 0.75	1.67 ± 0.25	1.57 ± 0.11	15.00 ± 1.70
CUK 49	2.00 ± 0.00	2.67 ± 1.23	1.50 ± 0.10	1.27 ± 0.15	1.30 ± 0.17	1.67 ± 0.11	1.50 ± 0.30	1.40 ± 0.20	24.47 ± 4.79
CUK 50	2.10 ± 0.17	2.43 ± 0.81	2.17 ± 0.40	1.70 ± 0.10	1.73 ± 0.51	1.50 ± 0.44	2.20 ± 0.40	1.70 ± 0.00	26.10 ± 1.91
Mean	2.47	3.59	2.22	2.19	1.77	1.57	2.10	1.75	51.31
Range	1 - 4	1 - 9	0.5 - 3.6	0.8 - 3.3	0.5 - 2.5	0.5 - 2.5	1.0 - 3.80	1.00-2.80	10- 135
SD	0.38	1.43	0.37	0.45	0.27	0.24	0.26	0.19	21.84
CV	15.38	39.83	16.67	20.55	15.25	15.29	12.38	10.86	42.56
CD @ 5%	0.48	1.32	0.84	1.01	NS	NS	0.41	0.23	14.79

**: significant at 1% level; *: significant at 5% level; NS: non significant

Table 4.17. Genotypic variance, phenotypic variance, GCV, PCV, heritability and genetic advance in the case of the growth and yield characters of *Kaempferia galanga* L.

Sl.No.	Characters	Geno-typic variance	Pheno-typic variance	GCV	PCV	Herit-ability	Genetic advance
1	Plant height	11.48	14.18	16.15	17.95	80.96	29.97
2	Number of leaves	47.79	63.33	31.84	36.68	75.46	57.02
3	Leaf length	4.64	5.74	14.44	16.12	80.84	26.84
4	Leaf breadth	1.55	1.99	14.99	16.91	77.89	27.13
5	Leaf area	488.47	599.54	25.38	28.12	81.47	47.19
6	Number of primary fingers	0.12	0.21	13.77	18.62	57.14	21.92
7	Number of secondary fingers	1.82	2.48	37.60	43.73	73.39	66.12
8	Length of primary fingers	0.05	0.32	9.91	25.68	15.63	8.27
9	Length of secondary fingers	0.08	0.46	12.79	30.14	17.39	10.80
10	Diameter of primary fingers	NS					
11	Diameter of secondary fingers	NS					
12	Length of mother rhizome	0.05	0.11	10.48	15.71	45.45	14.71
13	Diameter of mother rhizome	0.03	0.05	9.71	12.57	60.00	15.54
14	Yield per plant	449.73	531.75	41.34	44.94	84.58	78.31

4.2.1.2.2. Heritability of agronomic characters

Heritability (broad sense) is calculated as the ratio between genotypic variance and phenotypic variance and it gives the ability of the character to get inherited to its progeny. High heritability is shown by oligogenic characters and low heritability by polygenic characters. Most of the agronomic characters of the crop plants are polygenic in nature. They are influenced by the environment to some extent. The number of alleles involved and the extent of influence of environment decides the level of heritability. The fourteen agronomic characters studied in *Kaempferia galanga* presently showed different levels of heritability ranging from 15.63% to 84.58% (Table 4.17). The highest heritability was shown by yield per plant (84.58%) followed by leaf area (81.47%) and plant height (80.96%). Characters like number of leaves, leaf length, leaf breadth, number of secondary fingers and diameter of mother rhizome showed comparatively high heritability. Studies on heritability on *Kaempferia galanga* could not be traced by the present author. However, studies on heritability based on the nature of characters have been analyzed in the case of other crops like coconut (Ganesamurthy *et al*., 2002), turmeric (Narayanpur and Hanamashetti, 2003), cardamom (Radhakrishnan *et al*., 2006a), rice (Bharadwaj *et al*., 2007) and sorghum (Warkad *et al*., 2008).

4.2.1.2.3. Genetic advance under selection

Genetic advance is the quantum of improvement that is possible under selection (Allard, 1960). Fourteen agronomic characters of *Kaempferia galanga* have been analyzed presently for genetic advance (Table 4.17). The highest genetic advance was shown by yield per plant (78.31%) followed by number of secondary fingers (66.12%) and number of leaves (57.02%). Comparatively low genetic advance was shown by length of primary fingers (8.27%), length of secondary fingers (10.80%), length of mother rhizome (14.71%), diameter of mother rhizome (15.54%), number of primary fingers (21.92%), leaf length

(26.84%), leaf breadth (27.13%) and plant height (29.97%). Characters like number of leaves per plant (57.02%), leaf area (47.19%) and number of secondary fingers (66.12%) also showed comparatively high genetic advance. Genetic advance is an added advantage in selection and to make it more meaningful study of genetic advance to assess the quantum of improvement possible under selection was carried out by earlier workers in crops like rice (Nayak *et al*., 2004), cardamom (Radhakrishnan *et al*., 2006a), pea (Singh and Singh, 2006), coffee (Nikhila, 2007) and vanilla (Umamaheswari, 2008).

4.2.2. Correlation of characters

Agronomic characters of crop plants that are polygenic show different levels of correlation between them due to sharing of genes. Correlation between fourteen agronomic characters of *Kaempferia galanga* has been analyzed presently based on data collected from 50 accessions of the plant (Tables 3.2, 4.18 and 4.19). All the fourteen characters show significant positive correlation with each other indicating their mutual influence on other characters.

Earlier studies on correlation analysis in *Kaempferia galanga* could not be traced by the present author. However, studies on other members of the family Zingiberaceae have reported different levels of correlation between agronomic characters. Raveendra *et al.* (2001) have reported significant positive correlation between agronomic characters in *Curcuma longa*. Panja *et al.* (2002) also have reported similar results.

Tomar *et al.* (2005) have found that plant height, leaf length, thickness of primary and secondary rhizome and number of secondary rhizomes showed significant positive correlation with rhizome yield in *Curcuma longa*. Manohar Rao *et al*. (2006) have reported that weight of mother rhizome showed significant positive correlation with yield in turmeric.

Table 4.18. Correlation of characters in *Kaempferia galanga* L.

Characters	Plant height	Number of leaves	Leaf length	Leaf breadth	Leaf area	Number of primary fingers	Number of secondary fingers	Length of primary fingers	Length of secondary fingers	Diameter of primary fingers	Diameter of secondary fingers	Length of mother rhizome	Diameter of mother rhizome
Plant height	1												
Number of leaves	0.592374**	1											
Leaf length	0.958191**	0.608222**	1										
Leaf breadth	0.714857**	0.491616**	0.830884**	1									
Leaf area	0.869547**	0.553641**	0.951409**	0.955472**	1								
Number of primary fingers	0.371568**	0.700936**	0.507845**	0.640018**	0.576015**	1							
Number of secondary fingers	0.452449**	0.742595**	0.570549**	0.612965**	0.608224**	0.800517**	1						
Length of primary fingers	0.534463**	0.373486**	0.56748**	0.603306**	0.613831**	0.370123**	0.474827**	1					
Length of secondary fingers	0.557527**	0.406974**	0.62315**	0.65128**	0.668224**	0.458173**	0.543134**	0.873494**	1				
Diameter of primary fingers	0.380214**	0.287608**	0.46122**	0.576621**	0.540142**	0.44238**	0.477696**	0.845172**	0.797164**	1			

Diameter of secondary fingers	0.387718**	0.427488**	0.467591**	0.557585**	0.534052**	0.538615**	0.588504**	0.803806**	0.786464**	0.908784**	1		
Length of mother rhizome	0.573006**	0.352717*	0.596865**	0.614346**	0.628312**	0.309617*	0.358062**	0.687024**	0.668122**	0.433936**	0.379067**	1	
Diameter of mother rhizome	0.371466**	0.466235**	0.519746**	0.770173**	0.66086**	0.706643**	0.689531**	0.613255**	0.603529**	0.683971**	0.712024**	0.464891**	1
Yield per plant	0.359805**	0.720141**	0.493668**	0.679964**	0.595562**	0.808479**	0.8195**	0.520892**	0.534637**	0.530828**	0.640187**	0.446291**	0.858131**

*: significant at 5% level; **: significant at 1% level.

Table 4.19. Characters that show significant positive correlation in *Kaempferia galanga* L.

Character	Number of characters showing significant positive correlation	Characters correlated
Plant height	13	Number of leaves, Leaf length, Leaf breadth, Leaf area, Number of primary fingers, Number of secondary fingers, Length of primary fingers, Length of secondary fingers, Diameter of primary fingers, Diameter of secondary fingers, Length of mother rhizome, Diameter of mother rhizome, Yield per plant
Number of leaves	13	Plant height, Leaf length, Leaf breadth, Leaf area, Number of primary fingers, Number of secondary fingers, Length of primary fingers, Length of secondary fingers, Diameter of primary fingers, Diameter of secondary fingers, Length of mother rhizome, Diameter of mother rhizome, Yield per plant
Leaf length	13	Plant height, Number of leaves, Leaf breadth, Leaf area, Number of primary fingers, Number of secondary fingers, Length of primary fingers, Length of secondary fingers, Diameter of primary fingers, Diameter of secondary fingers, Length of mother rhizome, Diameter of mother rhizome, Yield per plant
Leaf breadth	13	Plant height, Number of leaves , Leaf length, Leaf area, Number of primary fingers, Number of secondary fingers, Length of primary fingers, Length of secondary fingers, Diameter of primary fingers, Diameter of secondary fingers, Length of mother rhizome, Diameter of mother rhizome, Yield per plant
Leaf area	13	Plant height, Number of leaves, Leaf length, Leaf breadth, Number of primary fingers, Number of secondary fingers, Length of primary fingers, Length of secondary fingers, Diameter of primary fingers, Diameter of secondary fingers, Length of mother rhizome, Diameter of mother rhizome, Yield per plant
Number of primary fingers	13	Plant height, Number of leaves, Leaf length, Leaf breadth, Leaf area, Number of secondary fingers, Length of primary fingers, Length of secondary fingers, Diameter of primary fingers, Diameter of secondary fingers, Length of mother rhizome, Diameter of mother rhizome, Yield per plant

Number of secondary fingers	13	Plant height, Number of leaves, Leaf length, Leaf breadth, Leaf area, Number of primary fingers, Length of primary fingers, Length of secondary fingers, Diameter of primary fingers, Diameter of secondary fingers, Length of mother rhizome, Diameter of mother rhizome, Yield per plant
Length of primary fingers	13	Plant height, Number of leaves, Leaf length, Leaf breadth, Leaf area, Number of primary fingers, Number of secondary fingers, Length of secondary fingers, Diameter of primary fingers, Diameter of secondary fingers, Length of mother rhizome, Diameter of mother rhizome, Yield per plant
Length of secondary fingers	13	Plant height, Number of leaves, Leaf length, Leaf breadth, Leaf area, Number of primary fingers, Number of secondary fingers, Length of primary fingers, Diameter of primary fingers, Diameter of secondary fingers, Length of mother rhizome, Diameter of mother rhizome, Yield per plant
Diameter of primary fingers	13	Plant height, Number of leaves, Leaf length, Leaf breadth, Leaf area, Number of primary fingers, Number of secondary fingers, Length of primary fingers, Length of secondary fingers, Diameter of secondary fingers, Length of mother rhizome, Diameter of mother rhizome, Yield per plant
Diameter of secondary fingers	13	Plant height, Number of leaves, Leaf length, Leaf breadth, Leaf area, Number of primary fingers, Number of secondary fingers, Length of primary fingers, Length of secondary fingers, Diameter of primary fingers, Length of mother rhizome, Diameter of mother rhizome, Yield per plant
Length of mother rhizome	13	Plant height, Number of leaves, Leaf length, Leaf breadth, Leaf area, Number of primary fingers, Number of secondary fingers, Length of primary fingers, Length of secondary fingers, Diameter of primary fingers, Diameter of secondary fingers, Diameter of mother rhizome, Yield per plant
Diameter of mother rhizome	13	Plant height, Number of leaves, Leaf length, Leaf breadth, Leaf area, Number of primary fingers, Number of secondary fingers, Length of primary fingers, Length of secondary fingers, Diameter of primary fingers, Diameter of secondary fingers, Length of mother rhizome, Yield per plant
Yield per plant	13	Plant height, Number of leaves, Leaf length, Leaf breadth, Leaf area, Number of primary fingers, Number of secondary fingers, Length of primary fingers, Length of secondary fingers, Diameter of primary fingers, Diameter of secondary fingers, Length of mother rhizome, Diameter of mother rhizome

4.2.3. Character association

Polygenic characters show different levels of association with each other due to the influence of the same sets of alleles on different characters. Grouping of characters based on this relationship is an effective tool to group them and also to find out lead variables in each group. This type of an approach is highly useful in reducing the bulk of variables that are being handled in crop improvement programmes. Character association in *Kaempferia galanga* has been analyzed presently using factor analysis. The study showed that all the 14 characters under study could be grouped under the same factor based on factor loading (Table 4.20).

Even though three factors could be identified, the other factors contributed very little towards the cumulative percentage of variance shown by the population when analyzed based on the characters under study (Table 4.21).

The study further showed that leaf area, leaf breadth, length of secondary fingers, leaf length and diameter of mother rhizome showed the highest factor loading and leaf area and leaf breadth could be identified as lead characters in the case of characters studied presently (Table 4.22). Even though no similar studies could be traced in *Kaempferia galanga*, character association has been studied in *Curcuma longa* by earlier workers (Manjunathgoud *et al*., 2001; Chattopadhyay *et al*., 2004; Tomar *et al.*, 2005 and Manohar Rao *et al*., 2006). However they observed that characters like plant height, size of primary and secondary rhizomes and weight of mother and finger rhizomes contributed the highest component towards character association. The present observation that leaf area is the lead character that could be considered in studying the interrelationship of characters in *Kaempferia galanga*, based on factor loading seems to be a new finding.

Table 4.20. Factor analysis in *Kaempferia galanga* L.- Factor Loadings

Character	Factor 1	Factor 2	Factor 3
Plant height	**.734252**	.214672	.579084
Number of leaves	**.690737**	-.465052	.220678
Leaf length	**.829652**	.130640	.499620
Leaf breadth	**.882795**	.031230	.216940
Leaf area	**.886411**	.106981	.374726
Number of primary fingers	**.742397**	-.544542	-.072195
Number of secondary fingers	**.788214**	-.460301	-.059868
Length of primary fingers	**.802619**	.429414	-.273044
Length of secondary fingers	**.829919**	.358859	-.205267
Diameter of primary fingers	**.758762**	.303679	-.486247
Diameter of secondary fingers	**.790649**	.128354	-.490424
Length of mother rhizome	**.675310**	.365977	.171690
Diameter of mother rhizome	**.828619**	-.189313	-.277077
Yield per plant	**.813436**	-.448418	-.190763

Table 4.21. Factor analysis in *Kaempferia galanga* L.– Eigen values and cumulative variance

Factors	Eigen value	Percentage of total variance	Cumulative Eigen value	Cumulative percentage of variance
1	8.780191	62.71565	8.78019	62.71565
2	1.592977	11.37840	10.37317	74.09405
3	1.566216	11.18725	11.93938	85.28131

Table 4.22. Factor analysis in the case of *Kaempferia galanga* L.- factors identified

Factors	Characters
1	**Leaf area, Leaf breadth, Length of secondary fingers, Leaf length, Diameter of mother rhizome,** Yield per plant, Length of primary fingers, Diameter of secondary fingers, Number of secondary fingers, Diameter of primary fingers, Number of primary fingers, Plant height, Number of leaves, Length of mother rhizome
2	Nil
3	Nil

4.2.4. Genetic divergence

Different genotypes of a plant species will show different levels of relationship between them based upon the genetic set up and habitats. Populations that are isolated usually show higher genetic distance. Even though chances of mixing up of genes are higher in sexually propagated crops, it is lesser in vegetatively propagated crops. However, there is scope for the origin of variations in vegetatively propagated crops also and these variations when they get established in their populations contribute towards the genetic diversity of the crop. Cluster analysis is an efficient tool to group the genotypes in a species into different clusters based on their affinities. The result of cluster analysis attempted presently in *Kaempferia galanga* is presented in Fig. 4.4 and Table 4.23.

The tree diagram obtained by UPGMA method shows that the genotypes of *Kaempferia galanga* studied presently could be grouped into 8 clusters at a linkage distance of 1. The I cluster consisted of 7 genotypes, II cluster was with 6 genotypes, III cluster with 7 genotypes, IV cluster with 6 genotypes, V cluster with 7 genotypes, VI cluster with 12 genotypes, VII cluster with 4 genotypes and VIII cluster with 1 genotype. CUK45 formed the VIII cluster with the maximum linkage distance from all the other clusters. Accession numbers CUK27 and

CUK29, accession numbers CUK6 and CUK12, accession numbers CUK13 and CUK15 were found to be the closest genotypes. Accession numbers CUK27 and CUK29 were collected from different geographical areas. However, the other two closely related groups, accession numbers CUK6 and CUK12 and accession numbers CUK13 and CUK15 were collected from nearby areas. This observation shows that geographical proximity is not always a reason for genetic similarity. Genotypes that are distantly related could be used in crop improvement programmes based on their phenotypic peculiarities.

Earlier studies on genetic divergence in *Kaempferia galanga* could not be traced by the present author. However such studies have been used as an effective tool to analyze the distance between different genotypes of crop plants by earlier workers like Bavappa and Mathew (1982) in arecanut, Radhakrishnan *et al.* (2006b) in cardamom, Golani *et al.* (2007) in brinjal, Umamaheswari (2008) in vanilla, Mehta and Asati (2008) in tomato, Sankaran *et al.* (2008) in lab lab bean and Sarkar *et al.* (2008) in barley.

Fig. 4.14. Genetic divergence in the 50 accessions of *Kaempferia galanga* L. studied- dendrogram

Dendrogram of the 50 accessions of *Kaempferia galanga* studied- details of accessions

1: CUK 1
2: CUK 2
3: CUK 3
4: CUK 4
5: CUK 5
6: CUK 6
7: CUK 7
8: CUK 8
9: CUK 9
10: CUK 10
11: CUK 11
12: CUK 12
13: CUK 13
14: CUK 14
15: CUK 15
16: CUK 16
17: CUK 17
18: CUK 18
19: CUK 19
20: CUK 20
21: CUK 21
22: CUK 22
23: CUK 23
24: CUK 24
25: CUK 25
26: CUK 26
27: CUK 27
28: CUK 28
29: CUK 29
30: CUK 30
31: CUK 31
32: CUK 32
33: CUK 33
34: CUK 34
35: CUK 35
36: CUK 36
37: CUK 37
38: CUK 38
39: CUK 39
40: CUK 40
41: CUK 41
42: CUK 42
43: CUK 43
44: CUK 44
45: CUK 45
46: CUK 46
47: CUK 47
48: CUK 48
49: CUK 49
50: CUK 50

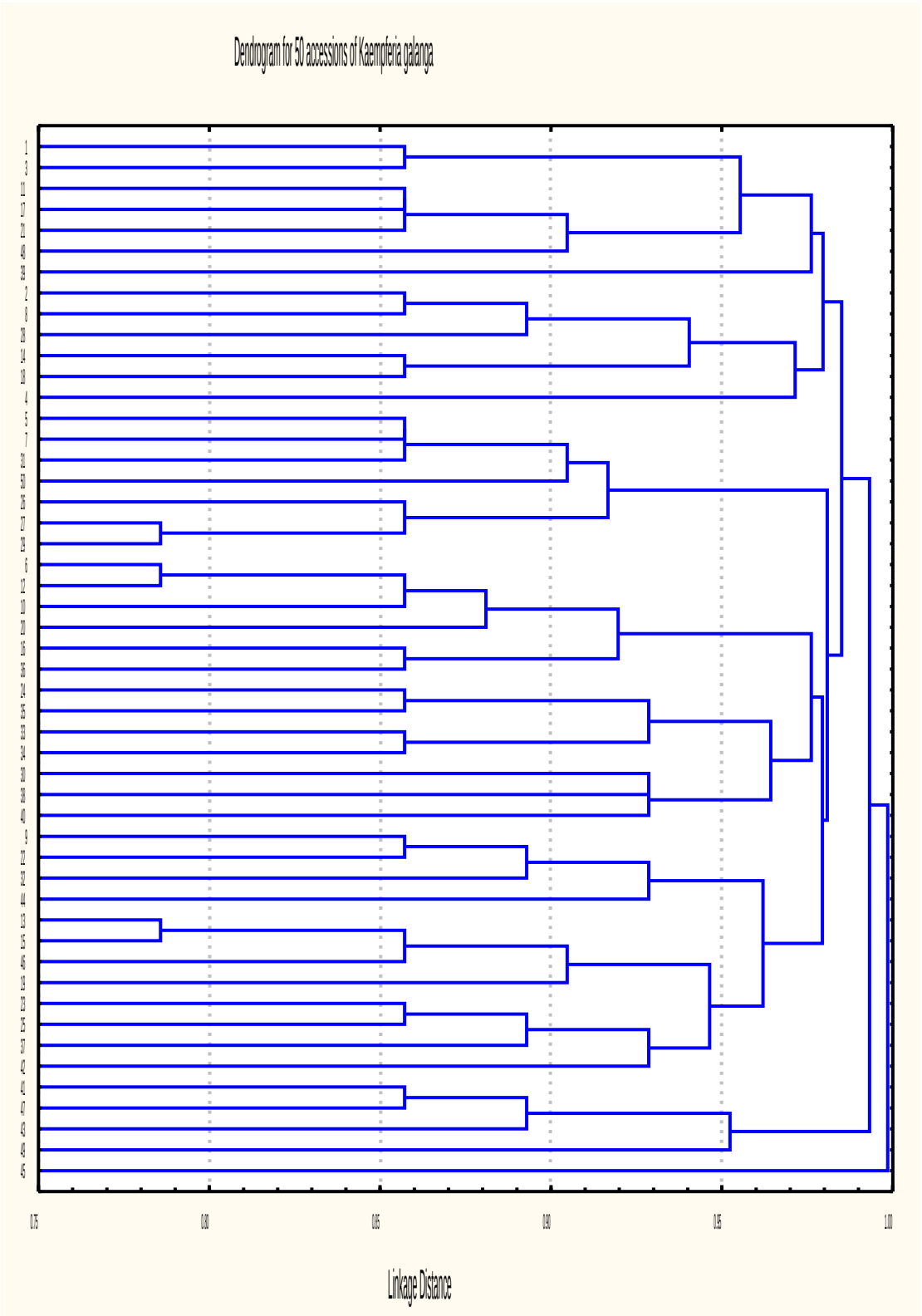

Dendrogram for 50 accessions of Kaempferia galanga
1
3
11
17
21
49
39
2
8
28
14
18
4
5
7
31
50
26
27
29
6
12
10
20
16
36
24
35
33
34
30
38
40
9
22
32
44
13
15
48
31
23
25
37
42
41
47
43
49
45
0.75
0.80
0.85
0.90
0.95
1.00
Linkage Distance

Table 4.23. Clustering of genotypes in the case of the accessions of *Kaempferia galanga* L. studied

Cluster No.	Genotypes
1	CUK 1, CUK 3, CUK 11, CUK 17, CUK 21, CUK 48, CUK 39
2	CUK 2, CUK 8, CUK 28, CUK 14, CUK 18, CUK 4
3	CUK 5, CUK 7, CUK 31, CUK 50, CUK 26, CUK 27, CUK 29
4	CUK 6, CUK 12, CUK 10, CUK 20, CUK 16, CUK 36
5	CUK 24, CUK 35, CUK 33, CUK 34, CUK 30, CUK 38, CUK 40
6	CUK 9, CUK 22, CUK 32, CUK 44, CUK 13, CUK 15, CUK 46, CUK 19, CUK 23, CUK 25, CUK 37, CUK 42
7	CUK 41, CUK 47, CUK 43, CUK 49
8	CUK 45

4.2.5. Performance analysis of *Kaempferia galanga* L. accessions collected

Comparative performance of the accessions of *Kaempferia galanga* collected for the present study has been analyzed based on major growth and yield characters as described elsewhere. Based no overall performance index, 10 genotypes of *Kaempferia galanga* have been selected presently for further studies leading to crop improvement. Among the 50 accessions, ranks 1-10 were assigned to CUK12, CUK10, CUK1, CUK14, CUK8, CUK16, CUK13, CUK4, CUK26 and CUK2 respectively. All the ten accessions selected presently show relatively good performance with comparatively good rhizome yield (Tables 4.24 and 4.25 and Figs. 4.15 to 4.24). Performance analysis has been carried out in several crops by earlier workers to isolate superior lines that could be used for further crop improvement programmes. Radhakrishnan (2003) conducted such studies in cardamom, Ramasubramanian (2005) in tea, Mini (2006) in rice, Hrideek (2007) in cardamom, Nikhila (2007) in coffee and Umamaheswari (2008) in vanilla. Their studies helped in the isolation of promising genotypes from the germplasms scanned for the purpose.

Table 4.24. Performance analysis of the accessions of *Kaempferia galanga* L. studied- character means

Acc. No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14
CUK 1	21.7	31.8	16.3	9.93	111.53	3.1	6.67	1.9	2.27	1.7	1.6	2.17	1.93	88.87
CUK 2	17.2	19.57	14.07	8.93	85.43	3.2	5.1	2.5	2.4	2.03	1.83	2.07	2.07	88.33
CUK 3	19.37	25.87	15.17	8.53	88.47	3.1	6.1	2.07	2	1.77	1.6	2.2	1.9	86.1
CUK 4	17.97	20.97	13.73	8.47	81	2.57	6	2.4	2.6	2.3	2.03	1.93	2.13	90.57
CUK 5	18.33	25.77	13.03	7.97	72.47	2.43	2.8	2.03	1.87	1.73	1.67	2.2	1.8	71.1
CUK 6	17.1	28.33	13.13	7.77	73.17	2.67	4.2	2.57	2.1	2	1.87	2.13	1.83	73.87
CUK 7	21.1	28.33	14.2	8.9	85.2	2.8	3.8	2.27	2.2	1.73	1.57	2.1	1.8	76.67
CUK 8	22.07	31.13	15.33	8.03	83.83	3.1	5.1	2.6	2.6	2.07	1.93	2.07	1.97	79.43
CUK 9	20.57	32	15.27	8.6	89.47	2.7	3.67	1.97	1.83	1.57	1.4	1.93	1.8	67.77
CUK 10	22.33	35.3	16.23	8.73	96.87	2.8	5.23	2.7	2.9	2	1.87	2.3	1.97	76.1
CUK 11	22.57	29.33	15.9	8.93	97.43	2.7	4.23	2.23	2.1	1.7	1.53	2.3	1.97	77.23
CUK 12	23.97	38.77	16.1	8.7	95.77	2.67	6.33	2.83	2.93	2	1.9	2.3	1.83	80.57
CUK 13	24	35.23	16.87	9.27	106.87	3.1	5.23	2.13	2.3	1.63	1.57	2.3	1.73	65
CUK 14	24.6	25.57	17.23	10.07	117.53	2.67	5.23	2.63	2.97	2.07	1.9	2.23	1.97	53.87
CUK 15	20.6	17.77	16.03	10.03	111.57	2.8	4.23	2.13	2.2	1.63	1.47	2.3	2.03	61.67
CUK 16	23.37	25.9	17.07	9.6	112.27	2.9	5.57	2.53	2.7	2	2.03	2.03	1.73	55
CUK 17	21.37	20.2	15.3	10.07	104.97	2.57	3.77	2.23	2.5	1.7	1.43	2.5	1.9	71.1
CUK 18	22.43	21.47	16.13	9.47	103.8	2.9	4.13	2.63	2.53	2.13	1.93	1.87	1.97	63.9
CUK 19	19.6	18.23	14.8	8.57	89.77	2.43	3.47	2.13	2.23	1.57	1.47	2.2	1.83	55
CUK 20	22.2	18.57	15.2	8.37	87.7	2.33	3.23	2.87	2.53	2	1.7	2.5	1.83	50.53
CUK 21	24.47	25.77	16.87	9.7	111.9	2.57	4.77	2.27	2.1	1.7	1.47	2.33	1.77	56.1

CUK 22	21.3	25.1	15.03	9.37	97.03	2.9	4	2.3	2.23	2	1.4	2.17	1.8	51.13
CUK 23	21.43	20.53	15.37	9.27	97	2.8	5	2.1	2	1.57	1.43	2.07	1.73	59.47
CUK 24	21.9	17	16.47	9.6	107.9	2.43	3.8	2.73	3	2.3	1.8	2.17	1.93	53.33
CUK 25	19.9	16.1	14.33	8.1	81.7	2.33	2	2	2	1.57	1.4	2.13	1.67	45.57
CUK 26	23.83	24.53	16.43	9.73	109.67	2.43	3.1	2.83	2.9	2.13	1.87	2.43	1.87	63.9
CUK 27	19.2	19.1	14.17	9.03	87.33	2.43	2.1	1.73	1.67	1.73	1.5	1.87	1.87	46.1
CUK 28	25.8	16	17.5	9.63	115.07	2.2	2.77	2.4	2.4	2.13	1.97	2.07	1.9	52.2
CUK 29	24.13	24.67	16.83	8.93	102.27	2.43	3.57	2.17	1.97	1.73	1.53	2.1	1.87	55
CUK 30	23.1	14.1	16.63	8.93	101.47	2.33	2.23	2.73	3.3	2.03	1.67	2.87	1.7	38.9
CUK 31	26.53	22.87	17.1	9.6	112.13	2.2	3.9	2.77	2.6	1.73	1.6	2.57	1.8	60
CUK 32	17.43	20.33	12.23	6.5	54.77	2.23	1.43	1.7	1.83	1.5	1.4	1.83	1.43	24.43
CUK 33	25.87	23.63	17.07	8.73	101.57	2.53	2.33	2.1	1.73	1.6	1.33	2.17	1.67	40.57
CUK 34	25.77	20.63	18.13	9.87	122.57	2.33	2.77	2.63	2.43	2.07	1.77	2.17	1.67	46.1
CUK 35	27.37	31.47	17.77	7.77	94.7	2.23	3.8	2.2	2.17	1.67	1.47	2.17	1.6	41.1
CUK 36	25.1	24.1	17.83	8.87	108.53	2.33	4.47	2.47	2.37	2	1.6	2.03	1.7	45
CUK 37	23.47	22.67	16.33	8.1	92.07	2	3	2.13	2	1.5	1.33	2.1	1.6	40
CUK 38	24.8	24.77	16.83	8.2	94.9	2.67	4.87	2.27	2.5	1.93	1.67	2.27	1.67	41.67
CUK 39	25.13	27.23	17.1	7.77	90.53	2.9	3.77	1.77	2.13	1.43	1.43	1.9	1.63	42.23
CUK 40	18.37	13.1	13.33	8.27	74.77	2.33	2.67	2.1	1.97	1.93	1.63	1.97	1.73	29.43
CUK 41	17.6	9.67	12.97	7.3	65.3	1.77	2.23	1.93	1.47	1.33	1.13	2.03	1.57	17.2
CUK 42	18	15.1	12.53	6.47	57.27	2.1	2.1	1.7	1.47	1.57	1.33	1.9	1.4	20.57
CUK 43	18.37	13.8	13.3	6.97	63.7	1.9	2	1.47	1.53	1.27	1.13	1.8	1.4	20

CUK 44	14.77	10.8	10.7	5.53	41	1.67	1.43	1.97	1.93	1.57	1.3	2	1.37	19.47
CUK 45	15.73	12	11.07	5.73	46.13	1.8	1.8	1.67	1.6	1.23	1.2	1.73	1.43	19.43
CUK 46	15.33	14.57	10.97	6.2	46.87	2.2	1.9	2.13	2.03	1.63	1.4	1.97	1.4	21.7
CUK 47	14.57	10	10.47	6.3	46.57	2	1.3	1.43	1.53	1.33	1.13	1.4	1.47	16.67
CUK 48	14.17	7.2	9.9	6.13	41.7	2	1.23	2.03	1.87	1.7	1.53	1.67	1.57	15
CUK 49	16.1	17.33	11	5.4	43	2	2.67	1.5	1.27	1.3	1.17	1.5	1.4	24.47
CUK 50	16.87	12.77	11.33	6.3	50.23	2.1	2.43	2.17	1.7	1.73	1.5	2.2	1.7	26.1

1: Plant height; 2: Number of leaves; 3: Leaf length; 4: Leaf breadth; 5: Leaf area; 6: Number of primary fingers; 7: Number of secondary fingers; 8: Length of primary fingers; 9: Length of secondary fingers; 10: Diameter of primary fingers; 11: Diameter of secondary fingers; 12: Length of mother rhizome; 13: Diameter of mother rhizome; 14: Yield per plant.

Table 4.25. Performance analysis of the accessions of *Kaempferia galanga* L. studied- performance indices

Acc. No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	Overall perfor-mance index	Rank of perfor-mance
CUK 1	**1.03**	**1.46**	**1.09**	**1.19**	**1.28**	**1.26**	**1.86**	**0.86**	**1.04**	**0.97**	**1.02**	**1.03**	**1.10**	**1.73**	**16.92**	**3**
CUK 2	**0.82**	**0.90**	**0.94**	**1.07**	**0.98**	**1.30**	**1.42**	**1.13**	**1.10**	**1.15**	**1.17**	**0.99**	**1.18**	**1.72**	**15.87**	**10**
CUK 3	0.92	1.19	1.02	1.02	1.02	1.26	1.70	0.93	0.91	1.01	1.02	1.05	1.09	1.68	15.82	12
CUK 4	**0.86**	**0.96**	**0.92**	**1.02**	**0.93**	**1.04**	**1.67**	**1.08**	**1.19**	**1.31**	**1.29**	**0.92**	**1.22**	**1.77**	**16.18**	**8**

CUK 5	0.87	1.19	0.88	0.96	0.83	0.98	0.78	0.91	0.85	0.98	1.06	1.05	1.03	1.39	13.76	29
CUK 6	0.82	1.30	0.88	0.93	0.84	1.08	1.17	1.16	0.96	1.14	1.19	1.01	1.05	1.44	14.97	20
CUK 7	1.01	1.30	0.95	1.07	0.98	1.13	1.06	1.02	1.00	0.98	1.00	1.00	1.03	1.49	15.02	19
CUK 8	**1.05**	**1.43**	**1.03**	**0.96**	**0.96**	**1.26**	**1.42**	**1.17**	**1.19**	**1.18**	**1.23**	**0.99**	**1.13**	**1.55**	**16.55**	**5**
CUK 9	0.98	1.47	1.03	1.03	1.03	1.09	1.02	0.89	0.84	0.89	0.89	0.92	1.03	1.32	14.43	27
CUK 10	**1.06**	**1.62**	**1.09**	**1.05**	**1.11**	**1.13**	**1.46**	**1.22**	**1.32**	**1.14**	**1.19**	**1.10**	**1.13**	**1.48**	**17.1**	**2**
CUK 11	1.08	1.35	1.07	1.07	1.12	1.09	1.18	1.00	0.96	0.97	0.97	1.10	1.13	1.51	15.6	14
CUK 12	**1.14**	**1.78**	**1.08**	**1.04**	**1.10**	**1.08**	**1.76**	**1.27**	**1.34**	**1.14**	**1.21**	**1.10**	**1.05**	**1.57**	**17.66**	**1**
CUK 13	**1.14**	**1.62**	**1.13**	**1.11**	**1.23**	**1.26**	**1.46**	**0.96**	**1.05**	**0.93**	**1.00**	**1.10**	**0.99**	**1.27**	**16.25**	**7**
CUK 14	**1.17**	**1.18**	**1.16**	**1.21**	**1.35**	**1.08**	**1.46**	**1.18**	**1.36**	**1.18**	**1.21**	**1.06**	**1.13**	**1.05**	**16.78**	**4**
CUK 15	0.98	0.82	1.08	1.20	1.28	1.13	1.18	0.96	1.00	0.93	0.94	1.10	1.16	1.20	14.96	21
CUK 16	**1.11**	**1.19**	**1.15**	**1.15**	**1.29**	**1.17**	**1.55**	**1.14**	**1.23**	**1.14**	**1.29**	**0.97**	**0.99**	**1.07**	**16.44**	**6**
CUK 17	1.02	0.93	1.03	1.21	1.21	1.04	1.05	1.00	1.14	0.97	0.91	1.19	1.09	1.39	15.18	17
CUK 18	1.07	0.99	1.08	1.14	1.19	1.17	1.15	1.18	1.16	1.21	1.23	0.89	1.13	1.25	15.84	11
CUK 19	0.93	0.84	0.99	1.03	1.03	0.98	0.97	0.96	1.02	0.89	0.94	1.05	1.05	1.07	13.75	30

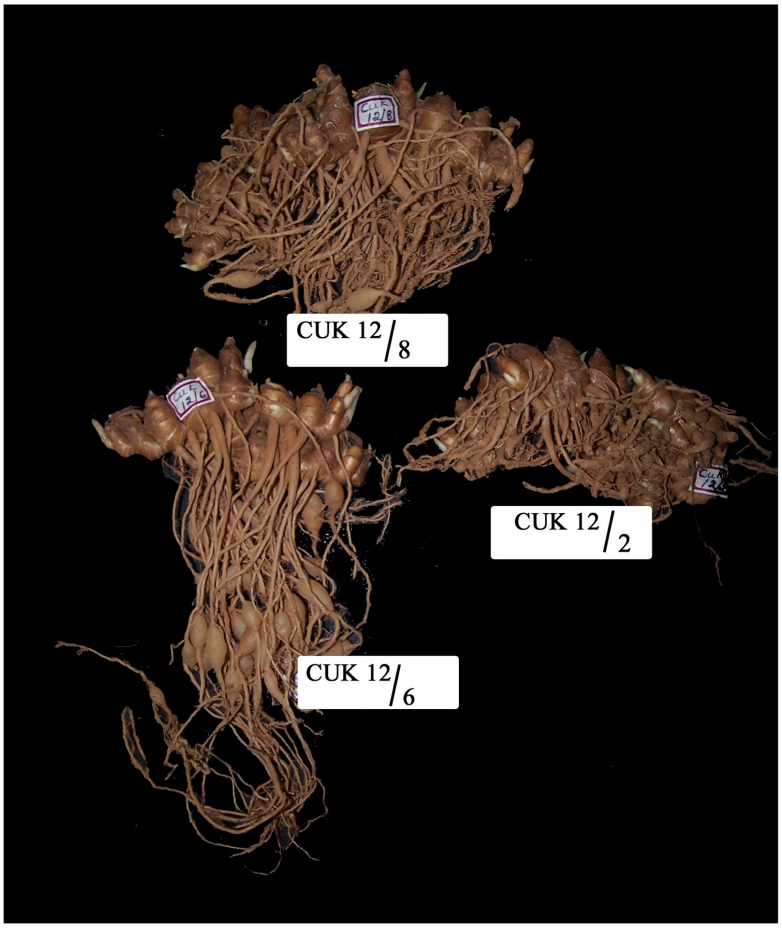
CUK 20	1.06	0.85	1.02	1.00	1.01	0.94	0.90	1.29	1.16	1.14	1.08	1.19	1.05	0.98	14.67	24
CUK 21	1.17	1.19	1.13	1.16	1.28	1.04	1.33	1.02	0.96	0.97	0.94	1.11	1.01	1.09	15.4	16
CUK 22	1.02	1.15	1.01	1.12	1.11	1.17	1.11	1.04	1.02	1.14	0.89	1.03	1.03	1.00	14.84	22
CUK 23	1.02	0.94	1.03	1.11	1.11	1.13	1.39	0.95	0.91	0.89	0.91	0.99	0.99	1.16	14.53	26
CUK 24	1.04	0.78	1.11	1.15	1.24	0.98	1.06	1.23	1.37	1.31	1.15	1.03	1.10	1.04	15.59	15
CUK 25	0.95	0.74	0.96	0.97	0.94	0.94	0.56	0.90	0.91	0.89	0.89	1.01	0.95	0.89	12.5	34
CUK 26	**1.14**	**1.13**	**1.10**	**1.17**	**1.26**	**0.98**	**0.86**	**1.27**	**1.32**	**1.21**	**1.19**	**1.16**	**1.07**	**1.25**	**16.11**	**9**
CUK 27	0.92	0.88	0.95	1.08	1.00	0.98	0.58	0.78	0.76	0.98	0.96	0.89	1.07	0.90	12.73	33
CUK 28	1.23	0.74	1.18	1.15	1.32	0.89	0.77	1.08	1.10	1.21	1.25	0.99	1.09	1.02	15.02	19
CUK 29	1.15	1.13	1.13	1.07	1.17	0.98	0.99	0.98	0.90	0.98	0.97	1.00	1.07	1.07	14.59	25
CUK 30	1.10	0.65	1.12	1.07	1.16	0.94	0.62	1.23	1.51	1.15	1.06	1.37	0.97	0.76	14.71	23
CUK 31	1.26	1.05	1.15	1.15	1.29	0.89	1.09	1.25	1.19	0.98	1.02	1.22	1.03	1.17	15.74	13
CUK 32	0.83	0.94	0.82	0.78	0.63	0.90	0.40	0.77	0.84	0.85	0.89	0.87	0.82	0.48	10.82	37
CUK 33	1.23	1.09	1.15	1.05	1.17	1.02	0.65	0.95	0.79	0.91	0.85	1.03	0.95	0.79	13.63	31
CUK 34	1.23	0.95	1.22	1.18	1.41	0.94	0.77	1.18	1.11	1.18	1.13	1.03	0.95	0.90	15.18	17

CUK 35	1.30	1.45	1.19	0.93	1.09	0.90	1.06	0.99	0.99	0.95	0.94	1.03	0.91	0.80	14.53	26
CUK 36	1.20	1.11	1.20	1.06	1.25	0.94	1.25	1.11	1.08	1.14	1.02	0.97	0.97	0.88	15.18	17
CUK 37	1.12	1.04	1.10	0.97	1.06	0.81	0.84	0.96	0.91	0.85	0.85	1.00	0.91	0.78	13.2	32
CUK 38	1.18	1.14	1.13	0.98	1.09	1.08	1.36	1.02	1.14	1.10	1.06	1.08	0.95	0.81	15.12	18
CUK 39	1.20	1.25	1.15	0.93	1.04	1.17	1.05	0.80	0.97	0.81	0.91	0.90	0.93	0.82	13.93	28
CUK 40	0.88	0.60	0.90	0.99	0.86	0.94	0.74	0.95	0.90	1.10	1.04	0.94	0.99	0.57	12.4	35
CUK 41	0.84	0.44	0.87	0.88	0.75	0.72	0.62	0.87	0.67	0.76	0.72	0.97	0.90	0.34	10.35	40
CUK 42	0.86	0.69	0.84	0.78	0.66	0.85	0.58	0.77	0.67	0.89	0.85	0.90	0.80	0.40	10.54	39
CUK 43	0.88	0.63	0.89	0.84	0.73	0.77	0.56	0.66	0.70	0.72	0.72	0.86	0.80	0.39	10.15	41
CUK 44	0.70	0.50	0.72	0.66	0.47	0.68	0.40	0.89	0.88	0.89	0.83	0.95	0.78	0.38	9.73	43
CUK 45	0.75	0.55	0.74	0.69	0.53	0.73	0.50	0.75	0.73	0.70	0.76	0.82	0.82	0.38	9.45	44
CUK 46	0.73	0.67	0.74	0.74	0.54	0.89	0.53	0.96	0.93	0.93	0.89	0.94	0.80	0.42	10.71	38
CUK 47	0.69	0.46	0.70	0.76	0.53	0.81	0.36	0.64	0.70	0.76	0.72	0.67	0.84	0.32	8.96	45
CUK 48	0.68	0.33	0.66	0.74	0.48	0.81	0.34	0.91	0.85	0.97	0.97	0.80	0.90	0.29	9.73	43
CUK 49	0.77	0.80	0.74	0.65	0.49	0.81	0.74	0.68	0.58	0.74	0.75	0.71	0.80	0.48	9.74	42

CUK 50	0.80	0.59	0.76	0.76	0.58	0.85	0.68	0.98	0.78	0.98	0.96	1.05	0.97	0.51	11.25	36

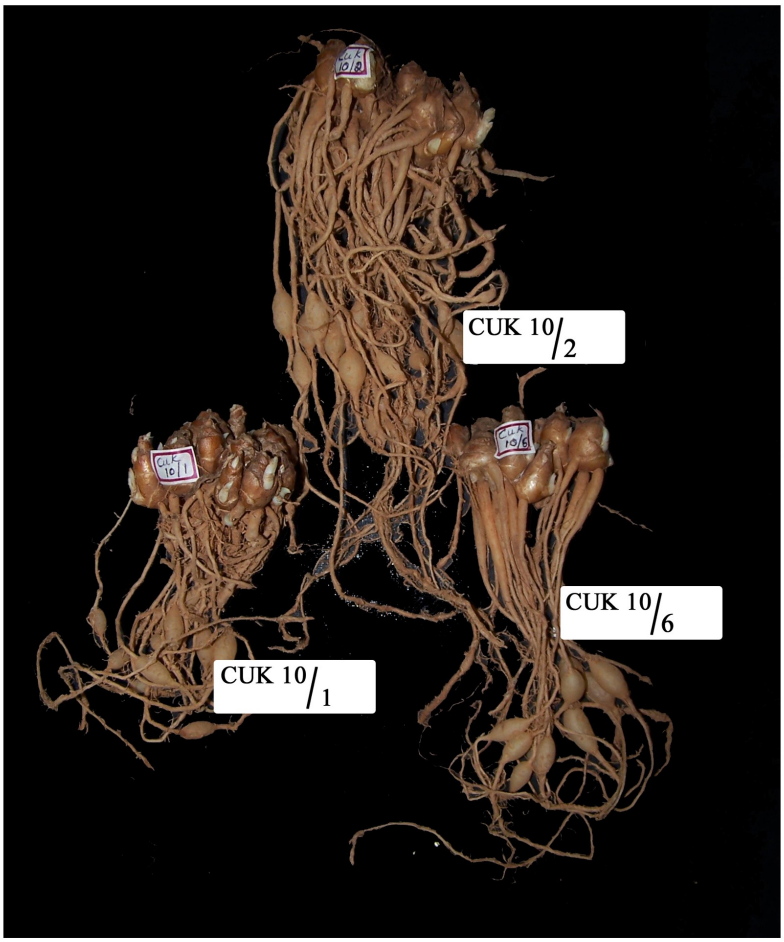
1: Plant height; 2: Number of leaves; 3: Leaf length; 4: Leaf breadth; 5: Leaf area; 6: Number of primary fingers; 7: Number of secondary fingers; 8: Length of primary fingers; 9: Length of secondary fingers; 10: Diameter of primary fingers; 11: Diameter of secondary fingers; 12: Length of mother rhizome; 13: Diameter of mother rhizome; 14: Yield per plant.

Fig. 4.15. Rhizome of *Kaempferia galanga* L. Accession No. 12
Rank No. 1



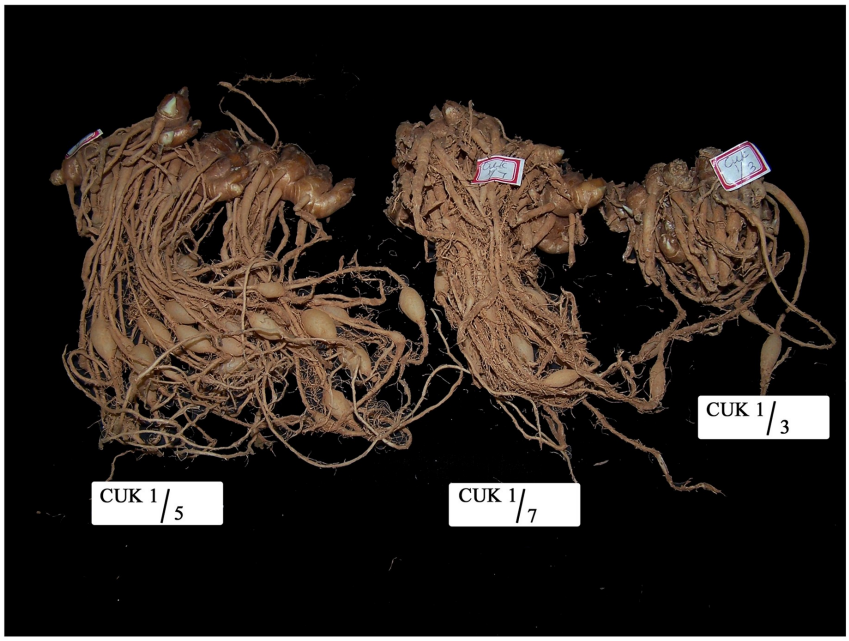
Plant height (cm)	:	23.97
Number of leaves	:	38.77
Leaf area (cm^2)	:	95.77
Number of primary fingers	:	2.67
Number of secondary fingers	:	6.33
Yield per plant (g)	:	80.57

Fig. 4.16. Rhizome of *Kaempferia galanga* L. Accession No. 10
Rank No. 2



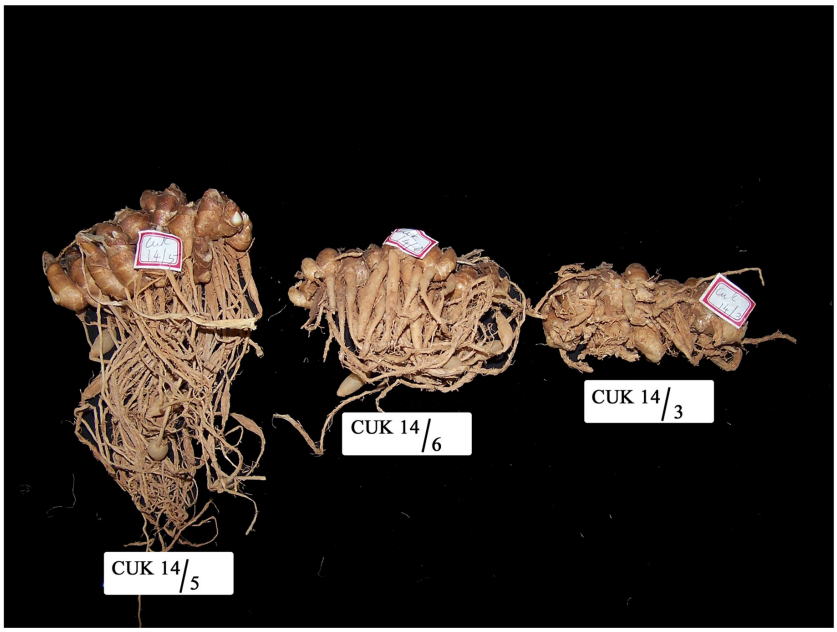
Plant height (cm)	:	22.33
Number of leaves	:	35.30
Leaf area (cm^2)	:	96.87
Number of primary fingers	:	2.80
Number of secondary fingers	:	5.23
Yield per plant (g)	:	76.10

Fig. 4.17. Rhizome of *Kaempferia galanga* L. Accession No. 1
Rank No. 3



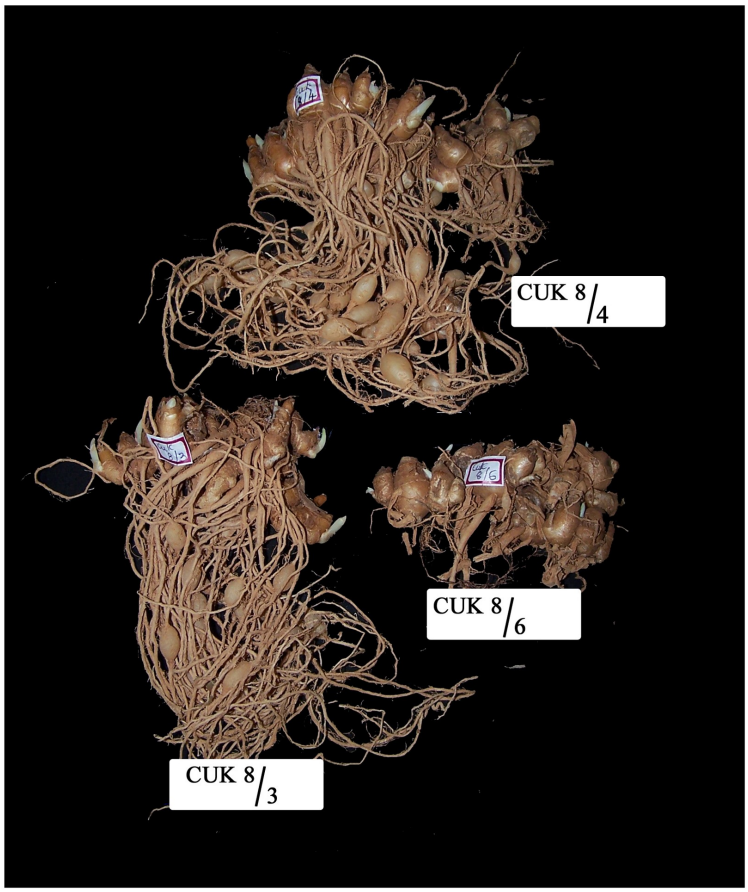
Plant height (cm)	:	21.70
Number of leaves	:	31.80
Leaf area (cm^2)	:	111.53
Number of primary fingers	:	3.10
Number of secondary fingers	:	6.67
Yield per plant (g)	:	88.87

Fig. 4.18. Rhizome of *Kaempferia galanga* L. Accession No. 14
Rank No. 4



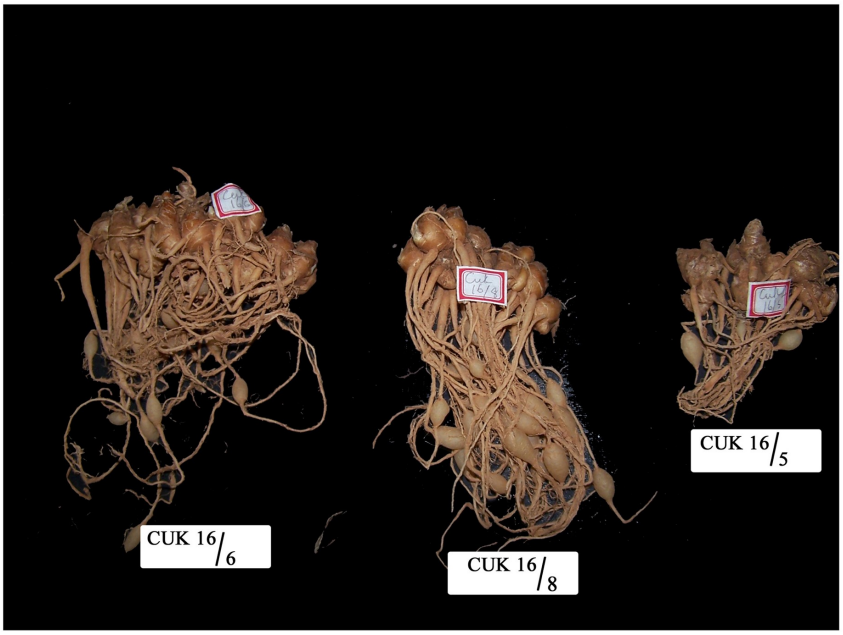
Plant height (cm)	:	24.60
Number of leaves	:	25.57
Leaf area (cm^2)	:	117.53
Number of primary fingers	:	2.67
Number of secondary fingers	:	5.23
Yield per plant (g)	:	53.87

Fig. 4.19. Rhizome of *Kaempferia galanga* L. Accession No. 8
Rank No. 5



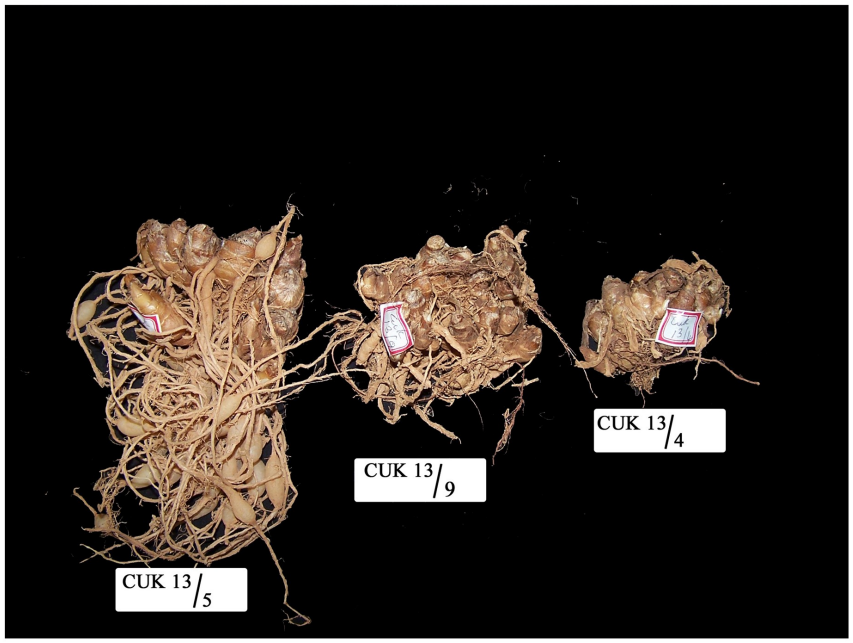
Plant height (cm)	:	22.07
Number of leaves	:	31.13
Leaf area (cm^2)	:	83.83
Number of primary fingers	:	3.10
Number of secondary fingers	:	5.10
Yield per plant (g)	:	79.43

Fig. 4.20. Rhizome of *Kaempferia galanga* L. Accession No. 16
Rank No. 6



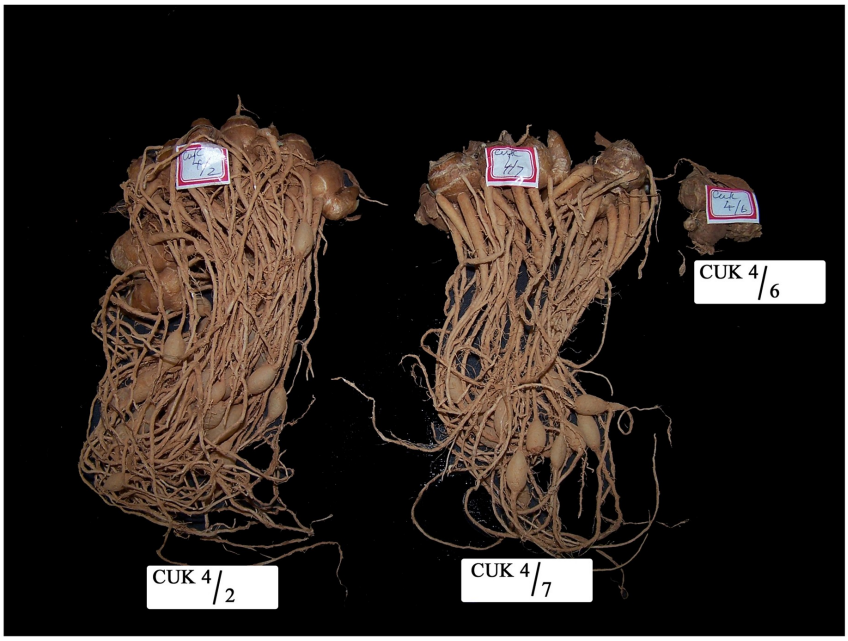
Plant height (cm)	:	23.37
Number of leaves	:	25.90
Leaf area (cm^2)	:	112.27
Number of primary fingers	:	2.90
Number of secondary fingers	:	5.57
Yield per plant (g)	:	55.00

Fig. 4.21. Rhizome of *Kaempferia galanga* L. Accession No. 13
Rank No. 7



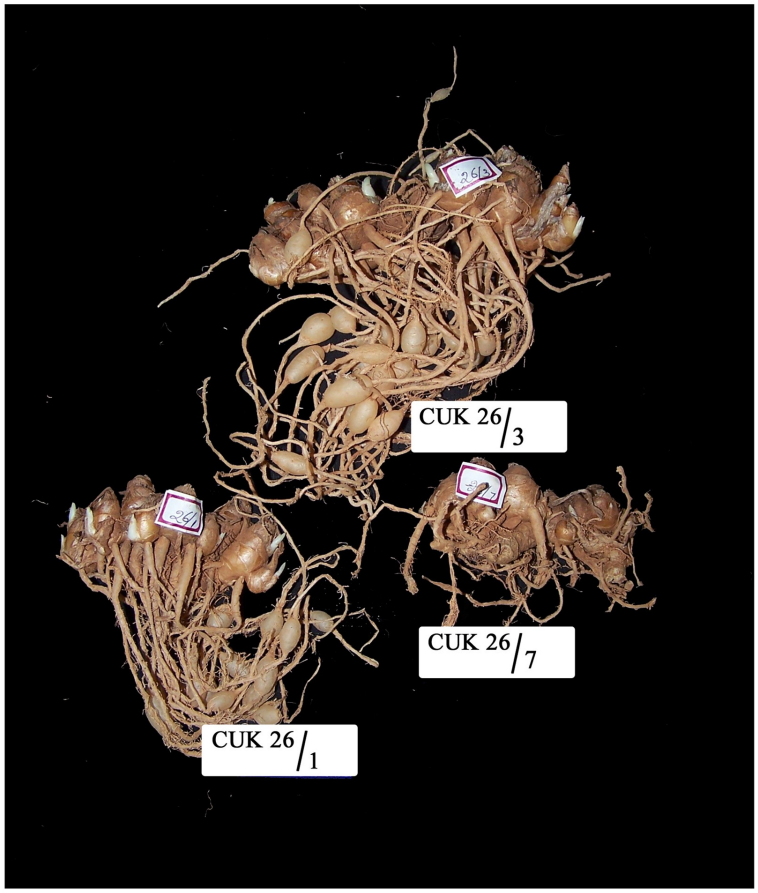
Plant height (cm)	:	24.00
Number of leaves	:	35.23
Leaf area (cm^2)	:	106.87
Number of primary fingers	:	3.10
Number of secondary fingers	:	5.23
Yield per plant (g)	:	65.00

Fig. 4.22. Rhizome of *Kaempferia galanga* L. Accession No. 4
Rank No. 8



Plant height (cm)	:	17.97
Number of leaves	:	20.97
Leaf area (cm^2)	:	81.00
Number of primary fingers	:	2.57
Number of secondary fingers	:	6.00
Yield per plant (g)	:	90.57

Fig. 4.23. Rhizome of *Kaempferia galanga* L. Accession No. 26
Rank No. 9



Plant height (cm)	:	23.83
Number of leaves	:	24.53
Leaf area (cm^2)	:	109.67
Number of primary fingers	:	2.43
Number of secondary fingers	:	3.10
Yield per plant (g)	:	63.90

Fig. 4.24. Rhizome of *Kaempferia galanga* L. Accession No. 2
Rank No. 10

Plant height (cm)	:	17.20
Number of leaves	:	19.57
Leaf area (cm^2)	:	85.43
Number of primary fingers	:	3.20
Number of secondary fingers	:	5.10
Yield per plant (g)	:	88.33

4.2.6. Study of performance based on the status of planting materials used

An experiment was carried out presently to find out the influence of the status of the seed material on growth and yield of the crop in *Kaempferia galanga* L. based on 50 plants each from mother rhizomes, primary fingers and secondary fingers. The observation showed that out of the fifteen characters studied, only four characters showed statistically significant difference in performance based on the status of the rhizome that was planted, which were mother rhizome, primary finger or secondary finger (Table 4.26). The characters that showed statistically significant variation were leaf length, leaf area, length of secondary fingers and diameter of mother rhizome. Other important parameters like leaf area, plant height, number of primary and secondary fingers and yield per plant did not show any statistically significant variation.

Some of the earlier workers have also reported that when mother rhizome was used as planting material higher yield was obtained in *Kaempferia galanga* (Rajagopalan and Gopalakrishnan, 1985a; Maheswarappa *et al*., 1999b; 2000b; 2001).

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Table 4.26. Growth and yield characters of *Kaempferia galanga* L. plants produced from planting materials of different status

Character	Mother rhizome			Primary fingers			Secondary fingers			CD
	Mean	Range	CV	Mean	Range	CV	Mean	Range	CV	
Days for germination	13.64	12 - 17	10.04	13.20	13 - 17	6.14	13.54	12 - 17	9.08	NS
Plant height (cm)	16.78	9.00 - 26.00	27.65	17.55	10.00 - 27.00	21.42	16.01	9.50 - 23.00	19.55	NS
Number of leaves	14.80	4 - 32	42.23	17.06	4 - 35	42.20	17.52	3 - 47	53.71	NS
Leaf length (cm)	12.39	7.50 - 19.33	21.07	13.01	7.83 - 18.10	17.29	11.82	6.67 - 17.67	15.74	3.68
Leaf breadth (cm)	8.70	4.90 - 12.00	14.93	8.74	5.83 - 10.83	14.41	8.41	5.33 - 11.23	14.27	NS
Leaf area (cm^2)	74.02	24.99 - 132.78	30.88	78.56	34.62 - 133.34	27.99	68.22	25.99 - 108.52	24.30	33.75
Number of primary fingers	2.32	2 - 3	20.26	2.46	2 - 4	23.58	2.22	1 - 3	22.97	NS
Number of secondary fingers	2.34	1 - 4	30.78	2.38	1 - 5	35.71	2.16	1 - 4	36.57	NS
Length of primary fingers (cm)	1.71	1.10 - 2.30	15.88	1.67	1.10 - 2.90	17.36	1.67	1.20 - 3.00	17.36	NS
Length of secondary fingers (cm)	1.61	1.20 - 2.13	12.30	1.73	1.07 - 3.00	23.12	1.57	1.27 - 2.50	19.12	0.51

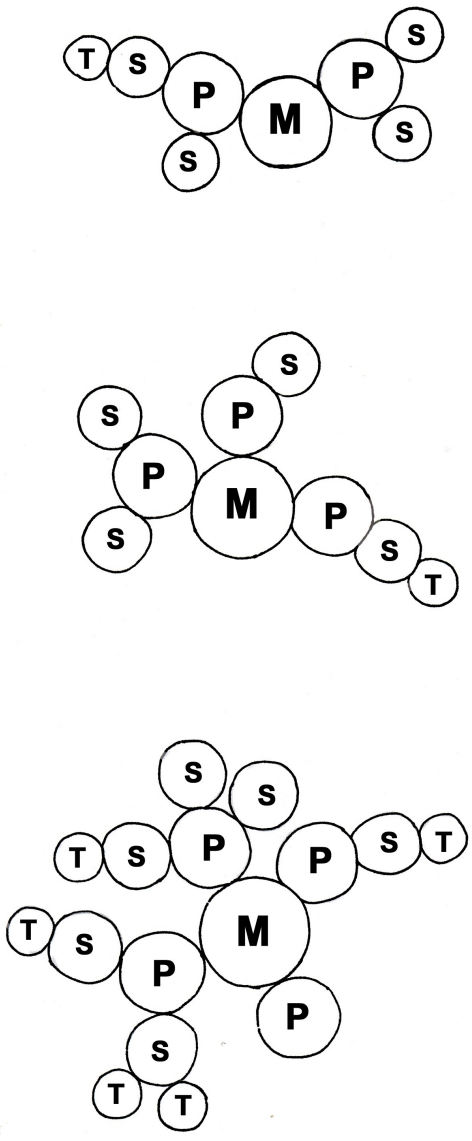
Diameter of primary fingers (cm)	1.66	1.37 - 2.00	10.63	1.67	1.20 - 2.10	12.57	1.62	1.30 - 1.93	9.88	NS
Diameter of secondary fingers (cm)	1.57	1.00 - 2.00	12.74	1.54	1.10 - 2.20	14.94	1.49	1.07 - 1.97	13.42	NS
Length of mother rhizome (cm)	1.76	1.20 - 3.00	20.45	1.72	1.20 - 2.60	19.19	1.66	1.00 - 2.80	20.48	NS
Diameter of mother rhizome (cm)	1.95	1.50 - 2.30	12.82	1.97	1.20 - 2.50	14.21	1.82	1.10 - 2.30	15.38	0.44
Yield per plant (g)	47.20	25 - 100	39.60	47.70	20 - 110	37.00	40.40	20 - 80	35.79	NS

4.2.7. Study of rhizome branching in *Kaempferia galanga* L.

Kaempferia galanga L. is an important medicinal and aromatic, rhizomatous herbaceous plant used in ayurvedic, unani and siddha medicines. The plant is propagated vegetatively using rhizome. The rhizomes contain essential oils and oleoresins that are used in perfumery and cosmetics. The branching pattern of the rhizome has been studied presently by observing the nature of rhizomes in the case of 50 accessions studied for genetic variability. Healthy rhizomes were used as seed material and they germinated within 12 to 17 days after planting and formed the first tiller which produced tuft of leaves and underground rhizome, the mother rhizome. The buds of this produced tillers and formed primary fingers. The number of primary fingers varied from 1 to 4 depending upon the number of buds developing to tillers. The primary fingers produced secondary fingers some of which in turn produced tertiary fingers. Thus in appearance the rhizome was having more or less globular to dome shaped fingers attached in a serial manner in different directions and the last formed terminal fingers were thinner and little elongated (Figs. 4.25; 4.26). Shah and Raju (1975) have attempted earlier to study rhizome branching in mango ginger and reported similar results. Mohanan and Pavithran (2007) studied tiller branching in rice and reported the nature of rhizome branching in rice as peripetal.

The present study in *Kaempferia galanga* L. shows that the pattern of branching is peculiar. In appearance the rhizome shows a number of more or less globular to dome shaped fingers arranged in 2, 3 or 4 directions in a manner of fingers joined end to end and the ultimate ones are smaller in girth than the preceding ones. The central one is considered the mother rhizome and the immediate ones from the mother rhizome are called primary fingers. From the primaries secondaries and tertiaries are formed in subsequent manner. The appearance of this type of rhizome pattern may be due to the formation of tillers from almost majority of the fingers of first and second order.

Fig. 4.25. Rhizome branching in *Kaempferia galanga* L. with 2, 3, and 4 primary fingers respectively



M: Mother rhizome; P: Primary finger; S: Secondary finger; T: Tertiary finger

Fig 4.26. Rhizome branching in *Kaempferia galanga* L.

Chapter V

SUMMARY AND CONCLUSION

Zingiberaceae forms an important group of angiosperms with economic potential and many members of this family yield spices, dyes, perfumes and medicines and some are ornamental. Many of them are used in ayurvedic and other native systems of medicine. Ginger, cardamom and turmeric of commerce are obtained from members of this family.

Curcuma amada Roxb., a member of this family, known as mango ginger in English and *karpuraharidra* in Sanskrit has got spice, food and medicinal values. The plant is a rhizomatous herb with palmate and sessile rhizomes united to the sides of an ovate conical bud which gives rise to leaves and spikes. The rhizome of mango ginger is characterized by the smell of fresh unripe mango and is regarded as cooling and used as carminative and stomachic. It has a long history of traditional uses ranging from folk medicine to several culinary preparations. It has antibacterial, insecticidal, antifungal and antioxidant properties.

Kaempferia galanga L. is another member of the family known as galangal in English and *sugandhavacha* and *chandramulika* in Sanskrit. It is a geophilous aromatic perennial herb with fragrant rhizomes and ovoid to spherical white tubers at the tips of fibrous roots. The rhizome is stomachic, anti inflammatory and used for dyspepsia, head ache and malaria. It is used by people of many regions of the world for relieving tooth ache, abdominal pain and rheumatism. The aromatic oil is used as condiment and as a folk medicine. Asians employ the rhizomes and leaves as a perfume in cosmetics and also as an insecticide.

Eventhough grown in the homestead gardens of Kerala on a limited scale, studies on the genetic behaviour of their gene pools and efforts to select superior genotypes so as to initiate crop improvement programmes are scanty in both the species. Moreover, urbanization of life styles has brought about new threats to their variability and existence both by way of eliminating such plants from the day to day use of people and by damaging their habitats.

The present experiments have been designed with the objective of analyzing the genetic variability, character association and genetic divergence of *Curcuma amada* Roxb. and *Kaempferia galanga* L. based on accessions collected from Kerala State of India so as to generate additional information and also to identify the best performing genotypes from them. A comparative study of the performance of the plants based on the status of planting material used has also been carried out so as to analyze the role of the status of the planting material in crop production. Study of rhizome branching in both the species has also been carried out so as to bring out the peculiarities in rhizome branching pattern.

The experiments were conducted in the experimental net house of the Genetics and Plant Breeding Division of the Department of Botany, University of Calicut, Kerala, India during 2005-2007. The experiments were laid out in randomized block design with three replications. Fifty accessions of *Curcuma amada* Roxb. and *Kaempferia galanga* L. collected from different locations in the northern districts of Kerala were used for the study. Data on growth, yield and rhizome characters were recorded in the case of both the species at the end of six months by destructive sampling. The data were analyzed so as to study the genetic variability, correlation of characters, character association, genetic divergence, over all performance of the genotypes, performance of plants based on the status of planting material used and rhizome branching pattern.

Study of frequency distribution gives a basic idea of the genetic control of characters and the nature of distribution of dominant and recessive alleles in the gene pools of the characters. The agronomic characters of *Curcuma amada* Roxb. studied presently showed continuous frequency distribution indicating polygenic genetic control. Plant height showed a balanced distribution of dominant and recessive alleles. In the case of length of primary fingers and diameter of secondary fingers, the frequency of dominant alleles was found to be higher as evidenced by the higher number of plants towards the second half of the frequency distribution. In the case of the other characters studied, the frequency of plants towards the first half of the distribution was found to be higher indicating the presence of higher number of recessive alleles in their gene pools and implying the necessity of selection of plants with desirable characters for crop improvement purposes. Even though plants with high yield were available in the germplasm, their frequency was very low. This shows that selection for yield and yield component characters is very essential in the genetic stock of *Curcuma amada* occurring in Kerala.

Phenotypic and genotypic variability of agronomic characters in *Curcuma amada* Roxb. has been studied presently based on six growth characters and nine yield characters. All the characters showed statistically significant variations between accessions. Among the growth characters the highest coefficient of variation was shown by number of tillers followed by leaf area and lowest coefficient of variation by number of leaves per tiller. Among the yield characters the highest coefficient of variation was shown by yield per plant.

In the case of all the characters studied in *Curcuma amada*, phenotypic coefficient of variation (PCV) was higher than genotypic coefficient of variation (GCV). This indicates additive polygenic nature of the characters. Among the growth characters the highest PCV was shown by number of tillers followed by

leaf area and the lowest by leaf breadth. Highest GCV was shown by leaf area followed by number of tillers and the lowest GCV was shown by number of leaves per tiller. Among the yield characters the highest PCV was shown by yield per plant and the lowest PCV by diameter of primary fingers. The highest GCV was also shown by yield per plant and the lowest GCV by diameter of primary fingers. Higher GCV indicates higher scope of inheritance of the character to the progeny and high difference between PCV and GCV indicates the influence of environment on the character.

Heritability (broad sense) is the ability of a character to get inherited to its progeny. Usually heritability will be high in the case of oligogenic characters and low in the case of polygenic characters. However most of the agronomic characters of crop plants are polygenic in nature and they are influenced by the environment to some extent and the number of alleles involved and the extent of influence of environment decides the level of heritability. Among the six growth characters and nine yield characters studied in *Curcuma amada*, plant height showed the highest heritability followed by leaf length and leaf area. Among the yield characters diameter of mother rhizome showed the highest heritability followed by yield per plant. Characters like plant height, leaf length, leaf area, diameter of mother rhizome and yield per plant showed high heritability. Characters like number of tillers, leaf breadth, length of primary fingers, length of secondary fingers, diameter of primary fingers, diameter of secondary fingers and length of mother rhizome also showed comparatively high heritability.

The quantum of improvement that is possible under selection can be calculated as genetic advance. It is the ratio between genotypic variance and phenotypic variance. Among the fifteen agronomic characters of *Curcuma amada* analysed presently, the highest genetic advance was shown by leaf area in the case of growth characters and yield per plant in the case of yield characters. Plant

height also showed comparatively high genetic advance and the lowest genetic advance was shown by number of primary fingers.

Most of the agronomic characters of crop plants are polygenic. These characters show different levels of correlation between them due to sharing of genes. Correlation between fifteen agronomic characters of *Curcuma amada* including six growth characters and nine yield characters were analyzed presently and it revealed that among the growth characters leaf area was showing significant positive correlation with twelve characters, leaf breadth was showing significant positive correlation with twelve characters, leaf length was showing significant positive correlation with eleven characters, plant height was showing significant positive correlation with eleven characters, number of leaves per tiller was showing significant positive correlation with three characters and number of tillers was showing significant positive correlation with one character. Among the yield characters length of secondary fingers showed significant positive correlation with twelve characters, number of primary fingers showed significant positive correlation with four characters, length and diameter of primary fingers showed significant positive correlation with eleven characters, number and diameter of secondary fingers showed positive correlation with eleven characters, length of mother rhizome showed significant positive correlation with eleven characters, diameter of mother rhizome showed significant positive correlation with ten characters and yield per plant showed significant positive correlation with eleven characters. Yield per plant showed significant positive correlation with plant height, leaf length, leaf breadth, leaf area, number of secondary fingers, length of primary fingers, length of secondary fingers, diameter of primary fingers, diameter of secondary fingers, length of mother rhizome and diameter of mother rhizome. However yield per plant did not show significant positive correlation with number of tillers, number of leaves per tiller and number of primary fingers. The information that yield per plant is positively correlated with other characters like plant height, leaf length, leaf breadth and leaf area provides a

tool to select high yielding accessions based on vegetative characters in *Curcuma amada*.

Polygenic characters show different levels of association due to the influence of same set of alleles on different characters. Grouping of characters based on this relationship is an effective tool to group them to different factors and to identify the lead characters so that further breeding programmes could be focussed on the lead characters selected. This type of an approach considerably reduces the bulk of variables that are being handled in crop improvement programmes. Character association in *Curcuma amada* was studied presently based on factor analysis using fifteen characters. Three factors contributing variations to the study population could be identified. However out of the fifteen characters, thirteen variables came under factor one and one variable under factor two. Factor three did not represent any of the variables studied presently and number of tillers did not contribute positive factor loading to any of these factors. In the 1st factor group, yield per plant had the maximum factor loading followed by leaf area and diameter of secondary fingers thus making them the lead characters in the group. The variable coming under the 2nd group was the number of leaves per tiller. Based on this analysis it can be observed that yield per plant, leaf area, diameter of secondary fingers and number of leaves per tiller could be used as lead characters in crop improvement programmes in *Curcuma amada*.

Different accessions of a plant species collected from different geographical areas will show different levels of inter relationship between them based on variations in characters. Genotypes that are spatially and reproductively isolated evolve in their own lines by incorporating hereditary variations interacting with the environment and also by reshuffling their genes by way of genetic recombination at the time of sexual reproduction. However, clonally

propagated plants have only limited scope for variation by way of genetic recombination. In such species also variations originate by mutations and such variations get inherited into the clonal progenies and undergo selection favourably or unfavourably depending upon the merit of variation. *Curcuma amada* is a clonally propagated crop and the variations that originate by mutation get inherited through clonal progenies of each and every population. Study of genetic divergence by cluster analysis provides an effective tool to classify genotypes based on their similarities and variations. The results of cluster analysis attempted presently in 50 accessions of *Curcuma amada* using fifteen agronomic characters show that the fifty genotypes could be grouped into eight clusters showing the genetic divergence of the genetic resources of *Curcuma amada* in Kerala. Cluster I consisted of 10 genotypes, cluster II of six genotypes, cluster III of 6 genotypes, cluster IV of 11 genotypes, cluster V of 5 genotypes, cluster VI of 6 genotypes, cluster VII of 4 genotypes and cluster VIII of 2 genotypes. Genotypes that are distant can be used for hybridization programmes. Selection can be practiced based on the merits of the genotypes as evidenced by the study of their performance.

A study of the over all performance of 50 accessions of *Curcuma amada* has been attempted presently based on performance index and cumulative performance index. Accession number CUM 34 ranked first with a cumulative performance index of 17.63 followed by CUM 35 with a cumulative performance index of 17.28. The accessions CUM 33, CUM 31, CUM 36, CUM 38, CUM 2, CUM 19, CUM 3 and CUM 32 ranked from 3 to 10 respectively. The superior accessions show significantly high level of agronomic characters and these accessions can be subjected to further selection procedures so that superior planting material is made available to the farmers.

Being a marginalized crop, improvement of yield potential in *Curcuma amada* L. is very important for popularization of the crop as food component and also for product diversification. Only one improved variety has been released from India. In Kerala, local cultivars are being used for cultivation and they show very high level of variability. Hence the development of improved varieties from the superior genotypes selected presently will be highly useful to the farmers.

In an experiment in which 150 plants of *Curcuma amada* were raised using mother rhizomes, primary fingers and secondary fingers taking 50 each as seed rhizomes to find out whether the status of the seed material selected had any role in the growth and yield of the crop. The influence of different types of planting material on sixteen growth/yield characters was observed. Ten characters showed statistically significant variations based on the status of the plant material used. The characters that showed statistically significant variations were days for germination, leaf length, leaf breadth, leaf area, number of secondary fingers, length of primary fingers, length of secondary fingers, diameter of primary fingers, diameter of mother rhizome and yield per plant. Mean days taken for germination, plant height, leaf length, leaf breadth, leaf area, number of secondary fingers, length of primary fingers, length of secondary fingers, diameter of primary fingers, diameter of mother rhizome and yield per plant showed comparatively higher values in the case of plants produced by mother rhizome and this difference was found to be statistically significant. Leaf length, leaf breadth, leaf area, diameter of primary fingers and diameter of mother rhizome showed higher values in the case of plants produced from primary fingers when compared with the plants from secondary fingers. The outcome of the experiment shows that when mother rhizome is used as planting material in *Curcuma amada*, growth and yield of the plants are generally higher when compared to the plants produced from secondary fingers.

Curcuma amada is a perennial herb with an underground branched rhizome born horizontally and aerial shoot with leaves. The plant is propagated vegetatively and viable rhizome pieces are used as planting material. The branching pattern of rhizome in *Curcuma amada* has been studied presently by observing the nature of rhizomes in the case of 50 accessions studied for genetic variability. When healthy rhizome fingers were used as planting material, seed rhizomes germinated within 7-20 days after planting and formed the first tiller which produced leaves. The base of the tiller became swollen and developed into the mother rhizome. From the mother rhizome primary branches developed towards different sides. The number of primary fingers ranged from three to six. The primaries produced secondaries and some of the secondary branches produced tertiary branches in turn. The primary branches showed positive geotropism in general. A few of the primary branches produced tillers in some cases making the tiller number varying from 1-4.

In the case of *Kaempferia galanga* L. also, 450 plants were grown for the study of frequency distribution of growth and yield characters and the plants were observed for growth and yield characters at the age of 180 days. All the agronomic characters of *Kaempferia galanga* analyzed presently showed continuous distribution showing polygenic genetic control. In the case of growth characters like plant height, leaf length, leaf breadth and leaf area, the number of plants with higher values was more when compared to the plants with lower values. In the case of number of leaves, number of secondary fingers, length of primary fingers, length of secondary fingers, diameter of primary fingers, diameter of secondary fingers, length of mother rhizome and diameter of mother rhizome, more number of plants showed values below the central value. Only a few plants showed high yield whereas majority of them showed yield levels below the central value. Selection of desirable genotypes with optimum expression of growth and other agronomic characters and maximum yield can be

adopted to improve the agronomic status of planting materials being made available to the farmers. However the entire diversity is to be conserved as such because *Kaempferia galanga* has been facing considerable levels of threat from damage of ecosystems and abandoning of conventional farming practices that have been necessitated by the new technologies and policies in the agriculture sector. Being a plant species with very high medicinal potential, the plant is to be conserved, improved and propagated more effectively.

Kaempferia galanga L. is a plant being cultivated in the homesteads of Kerala state for centuries on a marginal scale. However recent advances in the strategies and technologies of agriculture have resulted in further marginalization of the crop making it rare in the homesteads. Hence it was necessary that a genetic stock taking of the crop made and potential genotypes identified. The present study was designed for the above purpose. Phenotypic and genotypic variability of characters in *Kaempferia galanga* L. has been accessed presently based on five growth characters and nine yield characters. All the five growth characters studied presently showed statistically significant variations. Among the nine yield characters seven showed statistically significant variation between accessions.

Among the growth characters the highest coefficient of variation was shown by number of leaves followed by leaf area. Among the yield characters, the highest coefficient of variation was shown by yield per plant followed by number of secondary fingers. The lowest coefficient of variation was shown by diameter of mother rhizome. In the case of all the characters that showed statistically significant variation, phenotypic coefficient of variation was higher than genotypic coefficient of variation. This indicates additive polygenic nature of the characters. Among the growth characters, the highest phenotypic coefficient of variation was shown by number of leaves followed by leaf area. This shows that number of leaves is the most variable vegetative character in *Kaempferia*

galanga followed by leaf area. Genotypic coefficient of variation also showed the same trend of variation in the case of the growth characters. Among the yield characters, the highest PCV was shown by yield per plant followed by number of secondary fingers and lowest PCV was shown by diameter of mother rhizome. GCV also showed the same trend.

The fourteen agronomic characters studied in *Kaempferia galanga* presently showed different levels of heritability ranging from 15.63% to 84.58%. The highest heritability was shown by yield per plant followed by leaf area and plant height. Characters like number of leaves, leaf length, leaf breadth, number of secondary fingers and diameter of mother rhizome showed comparatively high heritability.

Fourteen agronomic characters of *Kaempferia galanga* have been analysed presently for genetic advance. The highest genetic advance was shown by yield per plant followed by number of secondary fingers and number of leaves. Comparatively low genetic advance was shown by length of primary fingers, length of secondary fingers, length of mother rhizome, diameter of mother rhizome, number of primary fingers, leaf length, leaf breadth and plant height. Characters like number of leaves per plant, leaf area and number of secondary fingers also showed comparatively high genetic advance.

Correlation between fourteen agronomic characters of *Kaempferia galanga* was analyzed presently based on data collected from 50 accessions of the plant. All the characters showed significant positive correlation with each other indicating their mutual influence on other characters.

Character association in *Kaempferia galanga* was analyzed presently using factor analysis. The study showed that all the fourteen characters under study could be grouped under the same factor based on factor loading. Even

though three factors could be identified, the other factors contributed very little towards the cumulative percentage of variance shown by the population when analyzed based on the characters under study. Leaf area, leaf breadth, length of secondary fingers, leaf length and diameter of mother rhizome showed the highest factor loading and leaf area and leaf breadth could be identified as the lead characters in the case of the characters studied presently.

.The result of cluster analysis attempted presently in *Kaempferia galanga* showed that the genotypes of *Kaempferia galanga* studied presently could be grouped into 8 clusters basecd on the characters studied. The I cluster consisted of 7 genotypes, II cluster was with 6 genotypes, III cluster with 7 genotypes, IV cluster with 6 genotypes, V cluster with 7 genotypes, VI cluster with 12 genotypes, VII cluster with 4 genotypes and VIII cluster with 1 genotype. Genotypes that are distantly related could be used in crop improvement programmes based on their phenotypic peculiarities.

Comparative performance of the accessions of *Kaempferia galanga* collected for the present study was analyzed based on major growth and yield characters. Based on overall performance index, 10 genotypes of *Kaempferia galanga* have been selected presently for further studies leading to crop improvement. Ranks 1-10 have been assigned to CUK12, CUK10, CUK1, CUK14, CUK8, CUK16, CUK13, CUK4, CUK26 and CUK2 respectively. All the ten accessions selected presently show relatively good performance with comparatively good rhizome yield.

The observation on the influence of the status of the planting material on growth and yield of the crop in *Kaempferia galanga* showed that out of the fifteen characters studied, only four characters showed statistically significant difference in performance based on the status of the rhizome that was planted, i.e., mother

rhizome, primary finger or secondary finger. The characters that showed statistically significant variation were leaf length, leaf area, length of secondary fingers and diameter of mother rhizome. Other important parameters like leaf area, plant height, number of primary and secondary fingers, etc. did not show any statistically significant variation.

The branching pattern of the rhizome has been studied presently by observing the nature of rhizomes in the case of the 50 accessions studied for genetic variability in *Kaempferia galanga* L. The rhizomes germinated within 12 to 17 days after planting and formed the first tiller which produced tuft of leaves and underground rhizome, the mother rhizome. The buds of this produced tillers and formed primary fingers. The number of primary fingers varies from 1 to 4 depending upon the number of buds developing to tillers. The primary fingers produce secondary fingers some of which in turn produce tertiary fingers. Thus in appearance the rhizome is having more or less globular to dome shaped fingers attached in a serial manner in different directions and the last formed terminal fingers are thinner and little elongated. The present study in *Kaempferia galanga* L. shows that the pattern of branching is peculiar. In appearance the rhizome shows a number of more or less globular to dome shaped fingers arranged in 2, 3 or 4 directions in a manner in which the fingers are joined end to end and the ultimate ones are smaller in girth than the preceding ones. The central one is considered the mother rhizome and the immediate ones from the mother rhizome are called primary fingers. From the primaries the secondaries and tertiaries are formed in subsequent manner. The appearance of this type of rhizome pattern may be due to the formation of tillers from majority of the fingers of the first and second order.

The above experiments were carried out so as to generate new and additional information on the genetic variability and genetic parameters of

agronomic traits, to select superior genotypes and also to study the role of the status of the planting material in crop yield and to analyse the rhizome branching pattern in two economically important underexploited members of the family Zingiberaceae namely *Curcuma amada* Roxb. and *Kaempferia galanga* L. It is hoped that the study has been useful in generating such information and also in selecting superior genotypes from the gene pools of the two species collected and conserved for the purpose.

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